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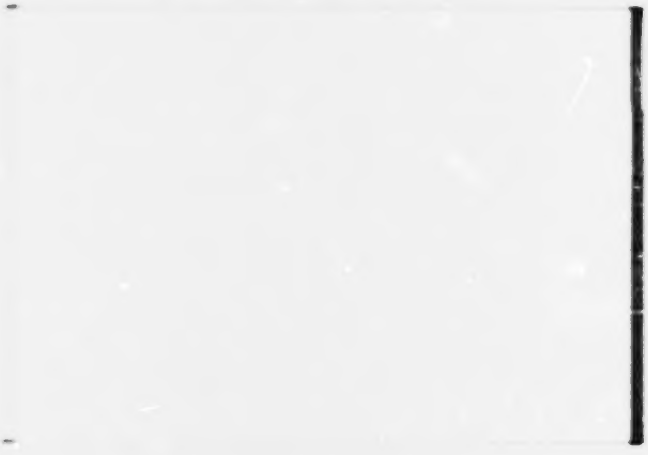

INVESTIGATION OF A TECHNIQUE TO REDUCE AIR LEAKAGE IN THE WALL CAVITIES OF OLDER HOMES

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by

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ABSTRACT

Methods of sealing both structural and interior finish leaks are desired in Canada for several reasons, including especially the restriction or prevention of exfiltration-condensation in the insulated structure ("conserving structures while conserving energy") and the restriction of inward transfers of possible emissions from deteriorating urea formaldehyde foam insulation (UFFI) where it has been used in houses. Focusing here on the latter, airless spray applications of polymeric encapsulants were developed in various modes of sealing, especially "drill-and-spray" and "open access" for sealing hidden structural leaks. The development and airtightness testing was done first on small mock-ups and test pieces, then tried and refined in some areas of old houses. Two UFFI'd houses with histories of formaldehyde transfer were then treated, "sealing off" the relevant leaks or leakage paths (by "structural sealing" the one house, "final entry point sealing" the other) using the spray-seal techniques. Airtightness characteristics were measured before and after treatment. Their performance into the following summer was then monitored to determine the efficacy of comprehensive sealing of connecting leaks in isolating the indoor air from the UFFI.

DISCLAIMER

This study was conducted by Scanada Consultants Limited for Canada Mortgage and Housing Corporation under Part V of the National Housing Act. The analysis, interpretations, and recommendations are those of the consultants and do not necessarily reflect the views of Canada Mortgage and Housing Corporation or those divisions of the Corporation that assisted in the study and its publication.

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SUMMARY

Working with small mockups and then actual houses, comprehensive spray sealing techniques were developed and refined to address certain problems presented by air leaks in existing houses. Sealing the leaks can restrict or avoid excessive exfiltration-condensation in the insulated structure ("conserving houses while conserving energy"). In the special case of urea formaldehyde foam insulation (UFFI), leak-sealing should greatly restrict the inward transfers of possible emissions from the foam - and that is the proposition addressed in this project.

The major leaks of concern are the hidden "structural leaks", usually located within the junctions where interior components (walls, floors, stairs, landings, etc.) are framed into the insulated exterior walls and roof spaces. Comprehensive sealing of these leaks was found to be feasible by **"structural sealing"** at the source, reaching into the structural intersections by means of "drill-and-spray" and "open access" operations, coating over the internal cracks and gaps using an airless spray gun and a polymeric encapsulant. "Stuffers" or gap fillers are used first to close larger gaps. (The mockup work suggested that polyurethane foam can sometimes do the gap-filling and final sealing in one application.)

Tests showed that difficult structural leaks are 93% to 97% air sealed by the spray-seal operation. Alternatively, the hidden air leaks can be stopped where they would finally enter (or exit from) the indoor air itself: **"final entry point sealing"**. Figure 1 illustrates some of the hidden leaks (structural leaks), final entry points and also the well recognized, easily sealed (but generally less important) "visible leaks" connecting directly from the insulated cavities to the indoor air. Figures 2, 3 and 4 illustrate some of the important structural leaks.

Field proving of the UFFI-isolating efficacy of such sealing was done in a somewhat limited manner: only two UFFI'd houses could be found with transfers of formaldehyde gas high enough to allow much to be proved. From a "summer before" indoor air condition of about 0.17 ppm and 0.10 ppm formaldehyde, the two houses were sealed and brought down to a "summer after" condition of about 0.04 and 0.03 ppm, respectively. (Summer conditions produce the highest emissions from UFFI.)

Acknowledging certain limitations, it is concluded that **"spray sealing techniques are practicable and effective in sealing the hidden structural leaks leading inward from wall cavities, and such sealing** (in conjunction with "visible leak" surface sealing) **appears effective in greatly reducing transfer of formaldehyde gas from "bad" UFFI in those cavities. The inference is that any substance from the UFFI is similarly blocked from entering the indoor air. There are strong indications also that "final entry point sealing" can be effective for considerably less effort."**

INVESTIGATION OF A TECHNIQUE TO REDUCE AIR LEAKAGE IN THE WALL CAVITIES OF OLDER HOMES

1.0 INTRODUCTION

The last few years have seen the realization of two technical problems in housing, problems that have spurred work into the reduction of certain air leakages in older homes. One of these arises from the deterioration of urea formaldehyde foam insulation (UFFI), and the attendant concerns about the inward transfer of its decomposition products into the indoor air. A more insidious and ultimately more important problem arises from the outward transfer of moist indoor air through the structural cavities, depositing excessive condensate especially after the cavities are filled with insulation of any type. The latter problem is also plaguing some new housing.

This introduction describes some of the issues concerning both problems, while the body of the report is devoted to the UFFI-control aspect alone.

The concept under study is the sealing of cracks, gaps, joints or paths that allow air to pass from indoors to the structural cavities, or from the cavities to the indoors. These leaks can be separated usefully into two categories: those that are normally visible, and those normally hidden. Both types can allow copious transfer of air, and the air flows can carry considerable quantities of water vapour or other contaminants.

1.1 Conserving Structures While Conserving Energy

Recent work for CMHC has highlighted the extent and the nature of moisture induced problems in housing. One significant finding concerns the incidence of excessive moisture in the envelope

structure of the building, in new construction and also in insulation-retrofitted construction. Field research* has underscored three factors at play that are relevant to this study.

Firstly, **air flow through leakage cracks** and gaps is by far the major mechanism in transferring water vapour from indoors into the structural cavities. It therefore seems reasonable to assume that gases or fine particulates in the cavities can be carried indoors primarily by "piggybacking" on air flows infiltrating through the same leaks. (In the former case - water vapour transfer - direct diffusion through the interior finish is now known to play a rather insignificant role; its insignificance is thus inferred for the latter case as well. Hence the presence or absence of the usual "vapour barrier" or "air/vapour barrier" means very little: it scarcely reduces the overall rate of outward or inward transfer of water vapour or other gases or dusts, since it simply parallels the interior finish and does not extend over the main air leaks, as will be seen.)

Secondly, the **hidden leaks** (or "structural leaks", where interior components are framed into the exterior envelope struc-

*Arctic field work long ago confirmed that mass air transfer through actual leaks is the single important mechanism in transferring water vapour into insulated cavities; vapour diffusion, and vapour barriers per se, play a very small role (Platts, **Condensation Control in Stressed Skin and Sandwich Panels**, DBR/NRC paper, Forest Products Journal V. xii, n.9 September 1962). More recent field research, especially on exfiltration-condensation-plagued "flueless" electrically heated houses in Newfoundland, has helped to pinpoint the leakage paths and air pressure roles. From 1977 to 1981 the work was carried out for private industry, and then collated and analysed further for CMHC (Scanada, **Field Survey of Moisture-Troubled Walls in Newfoundland Houses**, prepared for CMHC, May 1981). Infrared thermography (simultaneously with fan depressurization to induce air leaks) revealed the hidden "structural leaks" rather clearly, and external thermography plus electrical resistance moisture probing reveals that the pattern of excessive structural condensation correlates with the pattern of structural leaks and visible leaks. The knowledge of leakage paths and air transfer roles then led to the proposal of comprehensive "plugging" as a basic remedial measure for significantly troubled UFFI houses.

ture) together comprise the major part of the total leakage opening. Such leaky intersections include the junction of the exterior wall and roof spaces with interior walls, floors, stairs and landings, bulkheads, flues, ducts, pipes and wires. The remaining leakage area is comprised of the visible leaks, including those at electrical outlets, baseboards and other trim, and fixtures.

Thirdly, most air movement through the house walls in winter has traditionally been **infiltration**, owing to the buoyancy effect and attendant exfiltration via the active chimney and the loosely constructed upper envelope. The house is naturally depressurized. This has helped critically in keeping the wall cavities relatively free from excessive condensation, or in drying them out relatively quickly where temporary exfiltration has deposited condensate. (Exfiltration can occur through the lee side walls in windy conditions.) If any type of insulation fills the cavities, condensation is more apt to occur (the cavity is colder) and the drying effect of infiltration will be retarded by the insulation. For these and related reasons of moisture control, it is now realized that induced depressurization is especially important in a highly insulated house; an active chimney or equivalent exhaust often proves to be a necessary safeguard.

On the other hand, the predominant and generally desirable infiltration through the walls tends to carry indoors any gases and dusts from the cavities - and the desirability of that is in question particularly in UFFI'd houses.

1.2 Houses with UFFI

Reducing the concentration in the indoor air of formaldehyde gas and other gases or fine dusts from UFFI can be done simply:

1) reduce the inward rate of transfer of the contaminants, or

2) increase the air change rate in the house to dilute the contaminants, or
3) do both.

While it is obvious that 1) could be accomplished by pressurizing the house, such a measure is generally avoided because pressurization (or even the gentle elimination of natural depressurization) can induce or allow excessive exfiltration-condensation and thence rotting of the structure. Accordingly, the usual control measures available for UFFI houses have been developed and proffered as safe, escalating steps that can be chosen according to the contaminant level (formaldehyde) found indoors or the level of concern about it:*

- seal all visible leaks (i.e. establish a leak-free envelope at the interior finish planes)
- provide compensating ventilation to maintain an input of fresh air at the same rate as naturally operative before sealing, or
- step up to mechanical ventilation at higher rates for more dilution, with heat recovery if desired.

There is a school of thought that the best choices in measures to control UFFI should be completely passive measures, i.e. not dependent on powered equipment, nor yet on particular weather conditions, to work effectively. The passive choices, for houses thought to be substantially troubled by UFFI breakdown, are basic-

*The "UFFI IN THE HOUSE" Guides on remedial measures were developed by Scanada Consultants for the National Research Council. Originally based largely on theory only, later field work has proven the efficacy of visible leak sealing with compensating ventilation. Field testing by UNIES in Winnipeg, for NRC, has confirmed indoor formaldehyde levels are indeed reduced by a third (on average, with substantial variations) by these actions. The draft Guides, and the more comprehensive sealing approaches reported herein, have formed primary bases for the "Training Manual on Corrective Measures for Residences Insulated with ... UFFI", Consumer and Corporate Affairs, Canada (ref. 4).

ally two: sealing off the large majority of leaks or removing the foam altogether. The latter course tends to be very expensive and disruptive, especially if done properly. Sealing the visible leaks alone has been found to be effective in reducing the transfers from UFFI by about one third. Thus a need was perceived to find ways to seal the more dominant leaks, the hidden structural leaks.

1.3 Benefits of Sealing

Rather comprehensive sealing of existing houses entails primarily the plugging of hidden leaks, and secondarily the visible leaks. The potential benefits are:

- reduction of heat energy loss
- provision of a house amenable to economic assurance of air quality through the use of a controlled ventilation/heat recovery system
- provision of a house envelope amenable to retrofit filling with insulation without moisture problems
- elimination of discomforting drafts
- for UFFI houses, substantial reductions in the inward transfer of any gases or dusts from the UFFI.

The last attribute is the subject of these investigations.

2.0 THE PROBLEM: RESTRICT INWARD TRANSFER OF UFFI EMISSIONS

The problem is twofold: Firstly, it is necessary to demonstrate that inward transfers are indeed greatly reduced by sealing the leaks from the cavities. Secondly, to determine if the techniques are realistically applicable and practicable for the broad range of house types, constructions, and details.

The hidden leaks or **structural leaks** are the critical challenge: they generally require locating, reaching, sealing and inspecting through an interior finish. The structural leaks, all within the junctions where interior components intersect with the envelope cavities, are of three basic types:

- **Shrinkage cracks**, of up to 3 mm wide, formed generally where wood framing shrinks but the nails don't, so that sheathing, interior finishes and adjacent members "stand off" the framing.

- **Tunnels**, often 3 - 12 mm wide and usually leading clear under the exterior wall, formed by the shrinkage between floor boards. It will be seen that the tongue-and-groove type of floor boards present tunnels that are especially difficult to seal fully.

- **Gaps**, outright pathways built-in to some types of construction; e.g. solid masonry, plank frame, and some balloon frame constructions present wide gap pathways (18 - 40 mm and more) where strapping spaces and wall cavities open directly into floors, stairwells and the like.

NB. - The important **visible leaks** from the wall cavities past the interior finish are easy to seal well, but the major leaks from the cavities directly through the floor to the basement below demand considerable attention. These latter are similar to the

structural leaks, and are included in the accessible "visible leak" category only when there is no basement ceiling in the way.

Figures 1 to 4 illustrate these leaks and the problem they present.

Sealing is difficult because the limited access often forces the operator to work "blind". Problems include those of before-and-after inspection and testing (just as important as the sealing work itself). The researcher or contractor must know immediately that the hidden leaks have indeed been reached and sealed adequately.

Long term proof of this or any UFFI remedial measure is the final problem, made difficult by the continuing indeterminancy of the UFFI concerns. Setting aside those exceedingly rare UFFI houses with unarguably high indoor concentrations of formaldehyde gas, researchers appear to agree that medical complaints in UFFI households do not correlate to the presence of that gas. There appears to be no agreement on what other emissions from UFFI, if any, are actually causing complaints. Therefore these engineering investigations must assume that the one known and measurable contaminant, i.e. formaldehyde, can be used as "proof" of effective sealing. **If its inward transfer proves to be restricted, presumably the transfer of any other gas or dust from the UFFI is likewise restricted.**

3.0 OBJECTIVES OF THE ENGINEERING INVESTIGATIONS

Broadly, the immediate objectives are to determine if certain comprehensive sealing techniques can reduce indoor formaldehyde concentrations in a "significantly troubled" UFFI house to those of a typical non-UFFI house. Specifically the objectives are to:

- bring forward, refine and try certain "spray seal" and other structural sealing techniques (as earlier postulated by Scanada) to determine their applicability and adaptability to a range of house types, constructions and details,

- demonstrate the effectiveness of the techniques in airtightening the UFFI'd cavities of house structures and in reducing formaldehyde levels indoors,

- develop and demonstrate an inspection method that will assure completeness of sealing, even of hidden structural leaks,

- assess the safety and durability of the materials used,

- prepare a guide for the householder/contractor who may wish to use the techniques,

- document the materials and time spent on actual houses to help reject or indicate the potential commercial cost of the treatment,

- develop judgements and recommendations on the general merits and applicability of the techniques, possible refinements and alternatives, and the areas that may merit further evaluations or demonstrations.

4.0 PROJECT DESIGN

The approach taken in these engineering investigations was entirely pragmatic: an applications engineering and field "proof of concept" approach with a minimum of new development or technology. Emphasis was placed upon -

- adopting (and adapting where necessary) well-established materials, equipment, and techniques, and inspection and test methods, having successful commercial histories in somewhat parallel usages,

- testing the applications and sealant effectiveness in realistic simulations of structural junctions (coupon tests), evaluating these by pressure/flow measurements, direct peel tests and so on,

- trying, refining and retrying all techniques, equipment and sealants in full scale "dry run" set-ups, developing procedures and skills before applying them in anyone's house,

- applying the techiques finally in UFFI houses having substantial indoor formadehyde histories,

- redesigning the investigations and procedures as the lab and field work dictated. (As will be seen, the study shifted in part to evaluate comprehensive "final entry point sealing" as well as structural sealing.)

- transferring the techniques and much of the work to a contractor as the full house work proceeded, to allow more realistic time and cost indications and a start at commercial cost projections,

- photographing, recording and testing periodically.

5.0 DEVELOPMENT AND TRIALS

In reporting the main stream developmental work, particular attention is given to the problems, solutions and limitations that proved to be important.

Perhaps the most difficult problem of all, as in other "UFFI remedial" projects, was to find significantly troubled houses to serve as meaningful test cases. The intent was to obtain at least two houses with relatively high UFFI-sourced formaldehyde concentrations indoors - **at least 0.3 ppm** in summer or 0.15 ppm in winter, - so that the demonstration of "sealing off" the leakage paths could prove its efficacy in no uncertain terms. Such houses could not be found for this or other projects. Somewhat less troubled houses were found with difficulty.

5.1 "Dry Runs" in Company Houses

Before any techniques were tried in private households, they were developed and "domesticated" in fullscale trials in company houses. Scanada's offices in Oakville and Ottawa proved excellent: both are 2½ storey solid masonry constructions, formerly single detached houses, with the upper storey of wood frame construction. Teams in each office worked simultaneously with different approaches, equipment, materials, and inspection and test methods, variously drilling or cutting into the buildings throughout the top storeys. Accessing, plugging, spray sealing and final patching and make-good operations were devised.

The workable approaches proved to be as follows. At this stage only **structural sealing** (of hidden leaks) was being investigated:

- **"Drill-and-spray"** techniques appeared adequate in reaching and sealing uncluttered **shrinkage crack** structural leaks.

Examples: almost all partition-to-exterior wall, stair-to-wall, and floor-to-wall if the subfloor is square edge boards (or plywood). Figure 5 illustrates the technique. Holes of 16 mm in diameter proved adequate, drilled through the interior finish into the leakage zone.

- **"Open access" spray** techniques may be required for complete sealing of floor-to-wall junctions where T & G boards form the subfloor. As seen in Figures 6, 7 and 8, the "tunnels" between such boards can not be fully sealed by spray from below. Drilling through each tongue and groove joint may be necessary to allow plugging of the tunnel, forming a dam through to the finish flooring at the wall line. Spray sealing then lines or plugs the underside of the tunnel where it reaches under the wall to the exterior sheathing. Such a tedious approach may be required only where absolute sealing is desired, rather than simply sealing all the major leakage paths.

- **"Open access" spray** techniques would probably be required where the leakage zone is cluttered or incorporates outright **gap** pathways (Figure 4). Open access to such junctions is gained by cutting a strip out of the flooring and subfloor (especially if the finish flooring is carpet or sheet material that can be rolled back) or out of the ceiling below. This approach obviously entails considerable labour and care. The investigators tried "drill and spray" **urethane foam** as an alternative to plug/seal such junctions without cutting open access strips, but during this project were discouraged by dubious bonding of the polyurethane to dusty (and cobwebbed and squirrel-nested) wood surfaces*.

The extensive trials on these old houses proved valuable in assessing the practicability of deploying heavy industrial equipment (particularly high pressure airless sprayers, Figure 9) in

*Following this project, later development and trials of a "drill and plug" technique, with controlled foaming of polyurethane, did prove highly encouraging (ref. 4).

the living areas of occupied houses. The use of, and choice of, certain optical fibrescopes for inspecting the hidden leakage junctions before, during and after sealing also evolved well during these trials. The complementary use of fan depressurization techniques with smoke pencil testing of leaks (in conjunction with the optical fibrescope to detect structural leaks within the hidden zones) developed as an effective on-the-job inspection and test method to assure completeness and thoroughness (Figures 10, 11). Section 5.3 presents the final choices of materials and equipment.

5.2 Coupon Tests

Sealant performance: The need for more definitive testing of the spray-sealing technique was met by the use of small test pieces or mockups designed for air pressure/flow testing. The pieces were formed of old lumber to replicate the geometry and shrinkage cracks of a small section of a difficult-to-seal junction, the wall-into-floor zone - Figures 2, 12. Incorporating both T & G and square edged subfloor boards, nine mockups were pressure-flow tested unsealed and sealed (a tenth was left unsealed as a permanent control). The test chamber and commercial pressure/flow test device is shown in Figure 12.

The small mockups were spray sealed with the three elastomers that had passed the preceeding "dry runs". Once cured, the pieces were pressure/flow tested. The sealant film's adherence to the substrate, solubility in water and general integrity were also assessed. Pressure/flow tests were repeated one year later. Sealant modifications and final choices (emanating from the first tests) are given in section 5.3.

The role of diffusion: The opportunity to determine the contribution of formaldehyde diffusion through interior finishes arose in the course of the work. Tests were privately devised and

carried out by J. Smelko in Cornwall, Ontario; such essential permeance determinations had not been available before. The results were acquired for this project (section 6).

5.3 Materials and Equipment

Spray Sealants: The trials and evaluations narrowed the field to four thixotropic spray emulsions, with the final choice made as follows:

- acrylic copolymer emulsion: penetrates and fills cracks, coats and adheres very well - but is somewhat brittle, re-emulsfies in water rather quickly and does not then re-polymerize reliably.

- synthetic rubber emulsion (Decadex Firechek): bridges cracks and coats substrates very well, forming the toughest, most resilient and waterproof coating or encapsulant - but does not penetrate cracks or adhere very well to dirty wood or concrete. Costly. Chosen for the first field trial.

- polyvinyl chloride and other similar emulsions (identified only by trade name): performs similarly to either or both of the above - but gives off strong odours when sprayed and/or is more costly.

- **polyvinyl acetate copolymer emulsion** (Ocean 666): penetrates, fills and/or bridges cracks well, adheres very well, forms a tough and resilient film which re-emulsifies in water very slowly (months) and re-polymerizes well - but "bubbles" somewhat upon curing in deep crevices. Smoke pencil testing indicated that the bubbles can connect and form slight leaks. The manufacturer thickened the emulsion (higher solids content), which proved to eliminate that problem but reduced the resilience of the cured film. The modified material, now

renamed **Ocean 6TS** (Ocean Chemicals, Ottawa and Toronto) was selected for the main usage in the field.

The above all have good performance histories over a number of years in such uses as linings for food freezer plants and food storage facilities, retrofit encapsulants for asbestos fibre insulation, mine tunnel linings, roof deckings (the synthetic rubber emulsion) and high-build coatings for a variety of applications.

The high pressure airless spray application offers a particular advantage in sealing old structures: dust, insulation fibres and most cobwebs and dirt are immediately blasted away or driven deeply into the cracks. The sealant is driven through to the substrate, the Ocean 6TS being particularly good at penetrating and adhering to wood, concrete, masonry and other materials encountered.

The exposure conditions are benign to all of the above. Ultraviolet light is absent, the old wood is dry and rough for good bonding, and the warm-side position of the sealant film helps ensure that it will remain dry (above the dew point at almost any time and condition) and will face relatively little temperature deviation or movement of the substrates.

The questions of safety and health were considered carefully. The use of water based emulsions avoids the usage hazards of solvents. The Decadex and Ocean 6TS form a fire retardant final coating and are used commercially as such. Canada Health and Welfare officials assessed these coatings for CMHC and concluded that none of their ingredients pose any threat to health.

Airless sprayer: The Graco 333 and Graco 433 proved fully suitable (Figure 9), as did the Hero 1100 C. Rated pressures of 2000 psi are required. The Graco was used throughout the field project, using the flat spray (9702 series) tips and extensions:

- in line tip,
- and 24 in. extensions: in-line, 40° bend and 90° bend,
- spray tips: orifices 0.021, 0.023, 0.026 and 0.028 in; fan angles of 30° to 110°

The Hero worked well with a 24 in. extension swivel tip, "roto clean", 0.015 in. orifice, 90° fan.

Optical Fibrescope: Only one proved fully suitable, markedly superior in clarity of view and depth of field to the others available for evaluation or trial:

Dionics Borescope model TEKF 8-535 with light source 375 (Figures 10 and 20) -

- infinite depth of field
- light is adequate after spraying the structural zone with white sealant such as Ocean 6TS
- can inspect whole joist space/header zone from one 20 mm hole drilled through floor or ceiling just 8 cm from the header, for example
- the length and rigidity is a drawback in some situations.

Smoke pencils proved adequate in testing the completeness of sealing, in conjunction with fan depressurization of the house (Figure 11), and with simultaneous inspection with the Borescope in the case of hidden structural zones.

Dust-free saw: Cutting into the structural leakage zones can be an extremely dirty, dusty job, especially if the interior finish is gypsum/sand plaster or even gypsum drywall. A working prototype "dust-free saw" was designed and constructed for this project, and proved capable of cutting smoothly through even 2 cm of plaster - with no dust (Figures 13, 21). The saw is described fully in a separate report (2). The prototype is based on a 7 in. (178 mm) double-insulated 1.1 kW circular saw, using a 24 tooth carbide tip blade or, where many nails or wire lath may be

encountered, a special 16 tooth carbide tipped blade. A canvas shroud surrounds the saw and is connected to a 0.77 kW industrial vacuum cleaner.

Caulkings for the visible leaks: In the living space, the clear silicone seals (Tremco, GE, Dap, etc.) are highly favoured for sealing all fine-line cracks around trim and the like - up to say 2 mm wide. Lack of paintability is their major disadvantage: the householder may not achieve an unbroken film of paint in future redecorating. Other elastic caulkings avoid that drawback but may be too odorous (until cured) for some householders. Sealing the wider visible leaks - say around stair landings and other areas where shrinking and cracking has opened up cracks of 3-15 mm - can be done well with the butyl caulkings. (Visible leak sealing has been dealt with in earlier reports and in ref. 4.)

5.4 Field Applications

Although four UFFI'd houses were worked upon, only the last two became trials for the efficacy of comprehensive sealing. The earlier houses were used only for field experience with visible leak sealing; they were scarcely affected by formaldehyde, and one had even been committed to having the UFFI removed. The latter two had high enough concentrations that comprehensive sealing should have a significant effect. A brief account of the case histories of these two houses is given below.

Case 1: 1½ storey platform frame house near Ottawa. Built in 1954, stucco exterior, 8 m x 9 m in plan, uninsulated. Hardboard, fibreboard and gypsum board interior finish, very nicely finished and maintained. Oil warm air heated. UFFI'd in 1979: all exterior walls including gables and the knee walls, the latter first sheathed with fibreboard to accept the injection of UFFI.

T&G board subfloors, very little basement ceiling, and basement sill-header space previously blocked-in by owner (mineral wool insulation and hardboard bulkheads).

Status:

The high indoor reading in the summer of 1981, after 18 hours closed-up, was 0.2 ppm formaldehyde by 2-hour NIOSH. This suggests a probably actual high of **0.3 ppm**. The householders were not disturbed, were not considering removal of UFFI, and indeed were not eager to have disruptive work done. Understandably, there was no eagerness to undergo drill-and-spray (let alone open access) sealing that would mar the wallpapers or finish floorings. Therefore, the trial measures that were chosen were: structurally seal only where interior finishes need not be broken; otherwise seal or spray-seal where the structural or hidden leaks would finally enter the living space or basement, as illustrated in Fig. 1.*

Measures applied:

The sealing application was designed to have little effect on air transfer from outdoors (leaving ample air change) plugging only the main UFFI-linked leaks and paths. Figures 14-19 illustrate the main work. The sealing included:

- all visible leaks, interior surface of exterior walls only, superstructure only. No trim or baseboard removed.
- structural leaks (gaps) under knee walls: blocked with rigid polystyrene insulation and then spray sealed with Decadex Firechek.
- basement header zone under exterior walls: T&G joints of subfloor were drilled and plugged (butyl), then whole zone

*With the success of this trial, this latter approach was developed logically as a **Final Entry Point Sealing** method (FEPS), a less rigorous alternative to Structural Sealing (ref. 8).

was spray sealed as above. Return air ducts were opened where necessary to seal this zone.

- under bathtub: all subfloor board joints were drilled, plugged and spray sealed as above.
- all holes for plumbing stacks, piping and other main breaks through the subfloor boards: stuffed with tightly rolled glass fibre batt and then spray sealed as above.

About 39 ℓ of the Decadex Firechek were used, spray coating the leakage zones to a depth of about 4 mm.

Major leaks between indoors and outdoors were left unsealed (a few linking to the UFFI'd wall cavities to some extent). They were:

- doors and windows
- second floor junction with (UFFI'd) gable wall
- partition leaks into the basement through the subfloor (partitions also link to the UFFI'd gable walls via the second floor) **and into the attic and roof spaces.**
- partition junctions with exterior walls
- all visible leaks connecting partitions to the living space
- five under-knee-wall joist spaces which could not be reached easily because of a bathroom.

The measures, dates, and results are summarized in section 6.

Case 2: 1½ storey slab-on-grade, solid masonry first storey with wood frame half-storey added later. About 8 m x 9 m in plan. Original bungalow built in 1954. Interior finish entirely gypsum plaster, in very good condition. Electric baseboard heated, with airtight wood stove located centrally and used extensively. UFFI'd throughout the solid masonry tiles and cavities.

Status:

Tested midsummer 1981: 0.1 ppm formaldehyde (NIOSH 2 hr., chromatropic acid) - actual reading probably 0.15 ppm. Householders anxious to sell, and the rip-out option would essentially demolish this very attractive small house. Although this case did not seem to warrant any extensive or costly measures (apparently experiencing little transfer of formaldehyde gas) it was decided to apply complete structural sealing simply because no significantly troubled case could be found.

Measures applied:

Again the sealing work was directed as strictly as possible toward UFFI-linked leaks, effecting a minimum of overall airtightening of the house. Figures 20-34 illustrate the structural sealing procedure:

- Structural seal: the entire top of the masonry wall, gaining access through the kneewall space flooring, the gable end second floor, the second floor ceiling (using the dust-free saw) and the stair landing. The variety of approaches was chosen partly for the experience, e.g. cutting through a ceiling vs. cutting through flooring and subfloor.
- Structural seal: drill and spray seal the partition ends (junctions with the exterior masonry wall), first storey only.
- Structural seal: drill and spray seal the junction of the masonry wall to the slab on grade, wherever it is hidden by the sleeper floor (which covers most of the house plan).
- Visible leak sealing: all leaks through interior surface of masonry walls (i.e. first storey only), including the junction of masonry wall to the slab on grade where the flooring is applied directly (shoe mold removed first).

- Visible leak sealing: stairway to masonry wall (from underneath, closet area) and "pantry" closet area.

About 58 ℓ of Ocean 6TS were consumed in the spray sealing, covering the leakage zones to about 4 mm in depth (ref. 3).

The following leaks between indoors and outdoors were not sealed:

- doors and windows
- gaps under the knee walls, (the capping of the masonry walls does **not** airtighten the house and does allow the knee wall spaces to remain open but "untainted")
- partition tops and ends leading into the attic and (knee wall) roof spaces, and into the upper gable wall
- the perimeter of the sleeper floor directly under the ground floor bathtub
- one partition/masonry wall junction obstructed by the DHW tank.

(The last two apparently linked into the UFFI'd masonry wall, but were not considered worth the trouble.)

Since probing by moisture meter revealed that the UFFI was wet in the lower part of the north wall, even in midsummer, vents were added in the outer brick wythe (Figure 34). All measures and results are summarized in section 6.

6.0 RESULTS

6.1 The Question of Diffusion

The results of the diffusion testing (ref. 1) indicate that diffusion of formaldehyde gas inward through the interior finishes can indeed account for only one tenth or less of the formaldehyde concentration in the indoor air of "technically troubled" (0.1 ppm) UFFI houses. "Piggybacking" on the air flows through actual leaks must therefore account for essentially all of the inward transfer in essentially all cases.

6.2 Leak-Sealing Efficacy

Figure 35 is an example pressure/flow graph taken from the wall-into-floor coupon testing (5.2). The results ranged from 93% to 97%, i.e. the wall-into-floor joint passed only 3 to 7% as much air after spray sealing as before. The commercial test rig (rotameter type) betrayed some system leakage and anomalies at very low flows; **probably the spray sealing efficacy ranged from 95-100% in these laboratory applications.** In the field, the efficacy might drop to 80-90%, as a judgement.

6.3 Applicability in the Field (and costs)

Given that all structural sealing that involves cutting new access through interior finishes is onerous, the investigations suggest that about 80% of the (linear extent of) hidden leakage zones can typically be reached without special effort. Combining that with the foregoing judgement of sealing efficacy, the inference is that **65-75% of airborne transfers via the structural leaks inward from the wall cavities are stopped by practicable structural spray-sealing.**

Combined with visible leak sealing of the interior finishes over the UFFI'd cavities, to complete the "sealing off" of the UFFI, the comprehensive sealing approach appears to entail **an overall cost of $4000-6000 for a small 1½ or 2 storey house** such as Case 2 (ref. 3).*

6.4 Overall Airtightening of the House**

	ELA, m^2 @ 10 pa	Q, l/s @ 50 pa	ac @ 50 pa
Case 1 as found -	.093	690.4	6.37
after UFFI sealing -	.089	612.15	5.71
Case 2 as found -	.085	624.0	9.0
after UFFI sealing -	.059	426.0	5.9

Although the intent was not to airtighten the house, the UFFI-related sealing airtightened Case 1 by 12% and Case 2 by 34%. (Comparing measured air change effect.)

6.5 Reduction in Indoor Formaldehyde Concentrations

The next four pages contain summaries of all actions, tests and results for Case 1 and Case 2, with graphs of the indoor test readings of formaldehyde concentrations. (All formaldehyde tests

*In the further field work (8), "Final Entry Point Sealing", "drill and spray", and polyurethane "drill and plug" sealing, taken to an apparently adequate extent and often combined with compensating "bypass" ventilation, entail total costs of about $3000-4000 for such a house.

**The test methods and calculation procedures were in accordance with draft CGSB 149-GP-10M as evolved to 16th Dec. 1982 inclusive, except that indoor temperatures were not recorded.

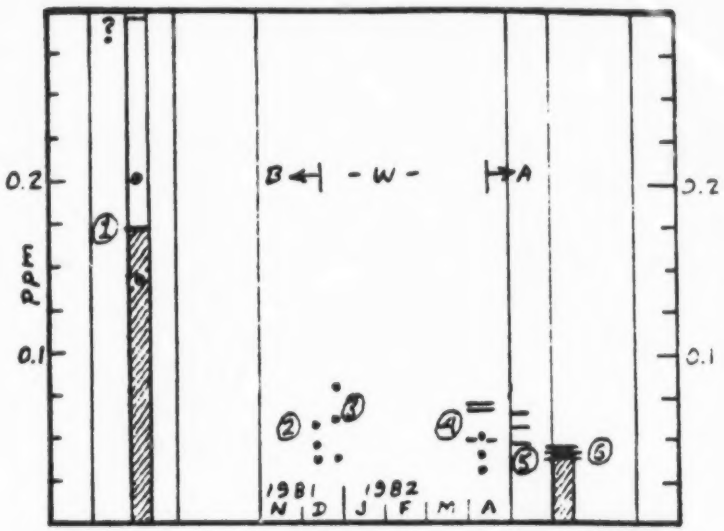
and dates are also tabulated in Tables 1 and 2.) Knowing that urea formaldehyde foam insulation outgasses relatively strongly in warm summer conditions (and may outgas very little through the winter), the meaningful test of remedial measures is to compare the summer after with the summer before the measures were applied, as on the graphs:

	Summer before	Summer after
Case 1	0.17 ppm avg., NIOSH (0.3 ppm probable actual)	0.04 ppm avg.
Case 2	0.085 ppm (fall) (0.15 ppm probable actual, summer)	0.03 ppm avg.

- as compared to typical **non-UFFI** house levels of 0.03 - 0.05 ppm.

CASE 1: 1½ St. Platform Frame, Stucco, 1954 8 m x 10 m plan. Oil, warm air. Much of interior finish is fibreboard, but well finished well maintained over the years. UFFI-filled exterior walls including upstairs gable walls and knee walls.

INDOOR FORMALDEHYDE



B - Before
W - Work Underway
A - After
(• NIOSH, - DOSIMETER)

Summary of tests taken and measures applied:
(tests numbered as on chart - ① ② ...)

28/8/81 Tests ① NIOSH 2 hr* LR 0.2 ppm, 2nd St. BR 0.14 ppm
Cavities, Drager** 10-2-2-7-8-7-0-0-10-0-7: summer condition

12/12/81 Tests ② NIOSH 2 hr LR 0.06, 1st St. BR 0.03, 2nd St. BR 0.04
Cavities, Drager 1-1-0-3-2-1--0-4--2: winter condition

17/12/81 Airtightness (flue etc. sealed for test) 7.02 ac/hr @ 50 Pa.

18/12/81 **"Visible Leak Sealing" ext. walls only**; not basement

21/12/81 Tests ③ NIOSH 2 hr LR 0.08, 1st St. BR 0.06, 2nd St. BR 0.04
Cavities, Drager --1-0-0-3-1--0-2--3-0-0

21/12/81 Airtightness (flue etc. sealed for test) 6.96 ac/hr @ 50 Pa.

Jan, Feb'82 **Under knee wall blocked** but not spray sealed (5 joist spaces obstructed by bathroom were **not** blocked or sealed)

2/3/82 Airtightness (flue etc. sealed for test) 6.67 ac/hr @ 50 Pa.
(Repeat with all windows sealed off, poly.) 5.86 ac/hr/50

- to 21/3/82 **Under knee wall spray sealed, all basement header-floor spray sealed (under ext. wall) and plumbing chases, chimney chase, return air duct ends (at header).** - "Final Entry Point Sealing"

22/3/82 Airtightness (flue etc. sealed for test) 6.13 ac/hr @ 50 Pa.
(Repeat with all windows sealed off, poly.) 4.85 ac/hr/50

-to 21/4/82 Leave all windows sealed (but house occupied).

14/4/82 Tests ④ NIOSH 2 hr LR 0.04, 1st St. BR 0.03, 2nd St. BR 0.04
Dupont Dosimeters 1 week, LR 0.07, 1st St. BR 0.07, 2nd St. BR 0.05
(Windows still sealed off with poly. and tape.)
Cavities, Drager 1-4-1-1-10-4--0-4-0-4-2--0

-to 7/5: Early "heat wave". Windows unsealed but generally closed. Upper floor windows kept closed always.

30/4 to 7/5 Tests ⑤ Dosimeters LR 0.05, 1st St. BR 0.05, 2nd St. BR 0.06
Cavities, Drager 10-4-3-7-10-7--0-4-0-7-2--0: summer condition
- Warm weather continues. Upper floor "occupied", some windows opened almost daily.

7/5 to 14/5/82 Tests ⑥ Dosimeters LR 0.04, 1st St. BR 0.04, 2nd St. BR 0.04

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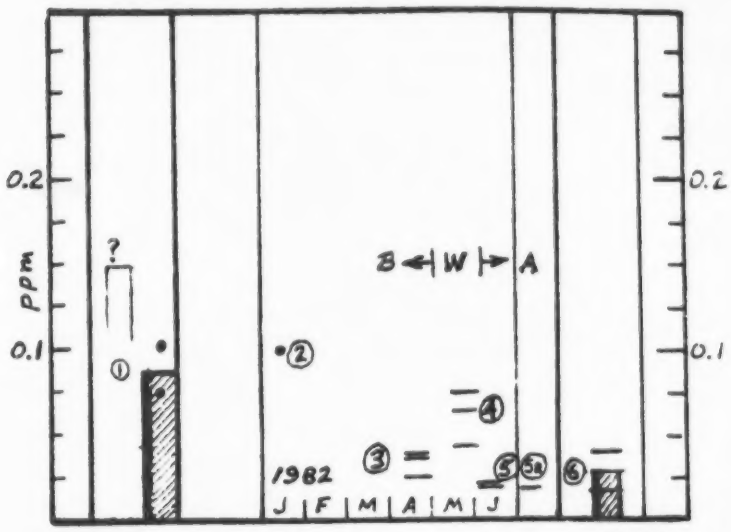
*NIOSH 2hr (sodium bisulfite): Tends to understate formaldehyde concentration by a third or so, hence the summer level was probably about 0.3 (18 hour close-up) as indicated by question mark on chart.

**Drager readings appear to overstate formaldehyde concentration in UFFI'd cavities by a factor of 4.

CASE 2: 1½ St. Slab-on Grade, Solid Masonry 1st St., Wood Frame Upper, 1950's. Gypsum plaster excellent condition. Electric baseboard, plus airtight wood stove. UFFI throughout the masonry tiles and cavities.



B - Before
W - Work Underway
A - After
(• NIOSH, - DOSIMETER)

SUMMARY of tests taken and measures applied:
(tests numbered as on chart - ① ② ...)

7/10/81 Tests ① NIOSH 2 hr*, 1st St. BR 0.07 ppm, 2nd St. BR 0.1
Cavity (walled-in window UFFI) NIOSH also, 5 ppm (equivalent to Drager rdg 20 or more - Dragers overstate*).
- UFFI wet. Removed from walled in windows (1st St. BR)

Jan. 82 Tests ② NIOSH 15 min (Québec Gov't), 0.1 ppm, location and date unspecified.
(Surprisingly high winter reading. Airtight stove contributing formaldehyde?)

28/1/82 Airtightness test by others (flue etc. sealed) 9.9 ac/hr @ 50 Pa.
29/1/82 **"Visible leak sealing"** by others.
Airtightness by others (flue etc. sealed) 7.0 ac/hr @ 50 Pa.

8/4/82 Owners approve "total seal" project. **House vacated now**, all furniture removed and owners clean house well.

15-22/4/82 Tests ③ Dupont dosimeters, DR 0.035, 1st St. BR 0.025, 2nd St. BR 0.036 (end-of-winter reading?)

30/4/- 19/5/82 Drilling, fibrescoping, **open access, capping and spray sealing of masonry walls and landing; drill and spray partition ends; seal under stairs and complete visible leak sealing in closets etc.**
- House completely closed up.

25/5 to 1/6/82 Tests (4) Dosimeters (DR 0.063, 1st St. BR 0.07, 2nd St. BR 0.042
- 1st. St. Bath, 2nd St. BR & Playroom: sliding window now opened 20 mm.

4/6/ to 11/6/82 Tests (5) dosimeters DR 0.021, 1st St. BR 0.021 ppm.

11/6/82 Airtightness (by same firm as before) (flue etc. sealed) 6.1 ac/hr @ 50 Pa.

14/6/ to 21/6/82 Tests (5a) dosimeter 2nd St. BR 0.016 ppm.

28/6/82 **Drill and spray seal perim. of masonry wall at junction with slab on grade** (drilling thorugh sleeper floor)
- Moisture probing: UFFI still wet in lower part of North masonry wall.

30/6/82 **Install vents at bottom of solid masonry N. wall.**
- Windows still slightly open, as 1/6/82.

6/7/ to 13/7/82 Tests (6) Dosimeters DR 0.040, 1st St. BR 0.029, 2nd St. BR 0.018
- summer high.

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*NIOSH (Chromotropic acid) may indicate formaldehyde adequately, but summer high was probably above this late October concentration, as indicated by question mark on chart.

**Dragers appear to overstate formaldehyde in UFFI'd cavities by a factor of 4.

7.0 DISCUSSION AND CONCLUSIONS

7.1 Limitations

The "proof value" of these investigations is somewhat limited because of the failure to find clearly troubled UFFI houses with which much could indeed be proved. (There is a corollary finding of value: clearly troubled UFFI houses appear to be exceedingly rare.) The results of these first trials do not invite great confidence* because

- only two full trial cases were done and assessed; how well do they present or represent the variety of materials, constructions, workmanships, exposures and usages that exist in the UFFI'd housing stock?

- the "before" condition was not firmly established; the investigators had to select houses on the basis of just one or two test methods and occasions, albeit in the worst (summer-fall) season, by other testers. (By the time two houses were found, the summer-fall period had passed and no further "before" tests could corroborate the peak indoor concentrations of formaldehyde.)

- since even these houses were not exhibiting very much formaldehyde contamination, it remains difficult to determine or infer relatively how much was contributed by the

*In succeeding field trials (ref. 4) the investigators have finally been successful in finding several clearly troubled cases, establishing their "before" condition more definitively, applying full sealing (structural and final entry point types) and partial sealing with bypass ventilation, and monitoring their indoor formaldehyde levels "after". Although these "Special Measures" trials must be monitored well into summer 1983 to obtain conclusive results, it does appear that they work completely effectively in careful but fully practicable application. A report will follow.

UFFI and how much from the usual other sources. Therefore it is impossible to conclude just how much "sealing off" was achieved. Since the apparent peak levels "after" were down to the typical values for non-UFFI houses - which vary considerably - the inference is that the sealing blocked almost all of the inward transfers from the UFFI. (Clearly the reduction could not be due to an increase in air change, since the overall **airtightening** effect was significant in Case 1 and substantial in Case 2, and only very minor provisions of summer ventilation were allowed during the last trials.)

- although the last indoor readings were taken with the cavity readings back to their previous summer high, more confidence would have been afforded by repeating the testing farther into summer. However the householders (who were far from exercised by the UFFI alarums) had had enough of visiting technicians and were politely discouraging further testing.

7.2 Conclusions

Given the limitations just outlined, the investigations and results indicate that spray-sealing techniques are practicable and effective in sealing the hidden structural leaks leading inward from wall cavities, and that such sealing (in conjunction with "visible leak" surface sealing) **appears effective in greatly reducing transfer of formaldehyde gas from "bad" UFFI in those cavities. The inference is that any substance from the UFFI is similarly blocked from entering the indoor air. There are strong indications also that "final entry point sealing" can be effective for considerably less effort.**

The overall airtightening effect of such sealing tends to be appreciable - even though the sealing work is directed to the

UFFI-linked paths alone - and therefore compensating ventilation measures will be desirable in many cases. Nevertheless the overall costs of such effective remedial measures can remain moderate. The investigators encountered no circumstances or conditions suggesting that UFFI emissions could not be prevented from entering the indoors. On this basis there would be no health-related ground for removal of UFFI as the only remedial choice.

Of real importance is the applicability of comprehensive spray sealing to the existing housing stock in general: This technique could form the basis of a practical method of achieving high degrees of airtightness in existing housing. The investigations show the practicability of reaching and sealing almost all leaks; mechanical ventilation with heat recovery then makes sense, and insulation and heating plant retrofit can be done with impunity and full effect.

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1. Diffusion of formaldehyde gas through the interior finish -- Memo of 5 March 1982 to C. Shirtliffe, NRC from R. Platts, Scanada, with calculations based on the work of J. Smelko.

2. The Dust-Free Saw: A Working Prototype - draft report prepared for CMHC by Scanada, 30 July 1982.

3. Preliminary Cost Projections on Sealing the Hidden Leaks - report prepared for CMHC by Scanada, 23 August 1982.

4. The Special Measures - draft manual for inspection and contractors, January 1983, based on 18-house trial of comprehensive sealing/compensating ventilation which followed these investigations. Final results will become clear in summer 1983. The basic sealing measures have been incorporated in the "Training Manual on Corrective Measures for Residences Insulated with ... UFFI", Consumer and Corporate Affairs Canada, "UFFI Centre", February 1983.

TEST #	DATE OF TESTS	ROOM AIR SAMPLING					WALL CAVITY SAMPLING															
		TEST TYPE		FORMALDEHYDE CONC. IN PPM.			TEST TYPE		FORMALDEHYDE CONCENTRATIONS IN PPM													
		NIOSH	DUPONT DOSIM	A	B	C	NIOSH	DRÄGER	1	2	3	4	5	6	7	8	9	10	11	12	13	14
①	28/08/81	✓		0.140	0.200			✓	10.0	2.0	1.5	7.0	8.0	7.0	<0.5	<0.5	10.0	<0.5	7.0	-	-	-
②	12/12/81	✓		0.043	0.055	0.033		✓	1.5	0.7	<0.5	3.0	1.5	1.0	-	<0.5	4.0	-	2.0	-	-	-
③	21/12/81	✓		0.036	0.079	0.065		✓	-	0.7	<0.5	<0.5	3.0	0.5	-	<0.5	1.7	-	3.0	<0.5	<0.5	-
④	14/04/82	✓		0.044	0.038	0.028		✓	1.0	4.0	0.7	0.7	10.0	4.0	-	<0.5	4.0	<0.5	4.0	1.7	-	<0.5
	14-21/04/82		✓	0.048	0.066	0.067																
⑤	30/4-7/5/82		✓	0.064	0.053	0.045																
	7/05/82							✓	10.0	4.0	3.0	7.0	10.0	7.0	-	<0.5	4.0	<0.5	7.0	2.0	-	<0.5
⑥	7-14/05/82		✓	0.040	0.041	0.042																

TABLE 1
Case 1: Room air sampling locations
A - 2nd storey bedroom
B - living room
C - master bedroom

TEST #	DATE OF TESTS	ROOM AIR SAMPLING					WALL CAVITY SAMPLING														
		TEST TYPE		FORMALDEHYDE CONC. IN P.P.M.			TEST TYPE		FORMALDEHYDE CONCENTRATIONS IN PPM.												
		NIOSH	DUPONT DOS/M.	A	B	C	NIOSH	DRÄGER	1	2	3	4	5	6	7	8	9	10	11	12	13	14
①	7/10/81	✓		0.095	0.070	–	✓		1.0	5.0											
②	?/01/82	✓		0.095 – UNSPECIFIED LOCATION																	
③	15-22/04/82		✓	0.025	0.035	0.036															
④	25/5-1/6/82		✓	0.042	0.063	0.075															
⑤	4-11/06/82		✓	–	0.021	0.021															
⑤a	14-21/06/82		✓	0.016	–	–															
⑥	6-13/7/82		✓	0.018	0.040	0.029															

TABLE 2
Case 2: Room air sampling locations
A - 2nd storey bedroom
B - master bedroom
C - dining room

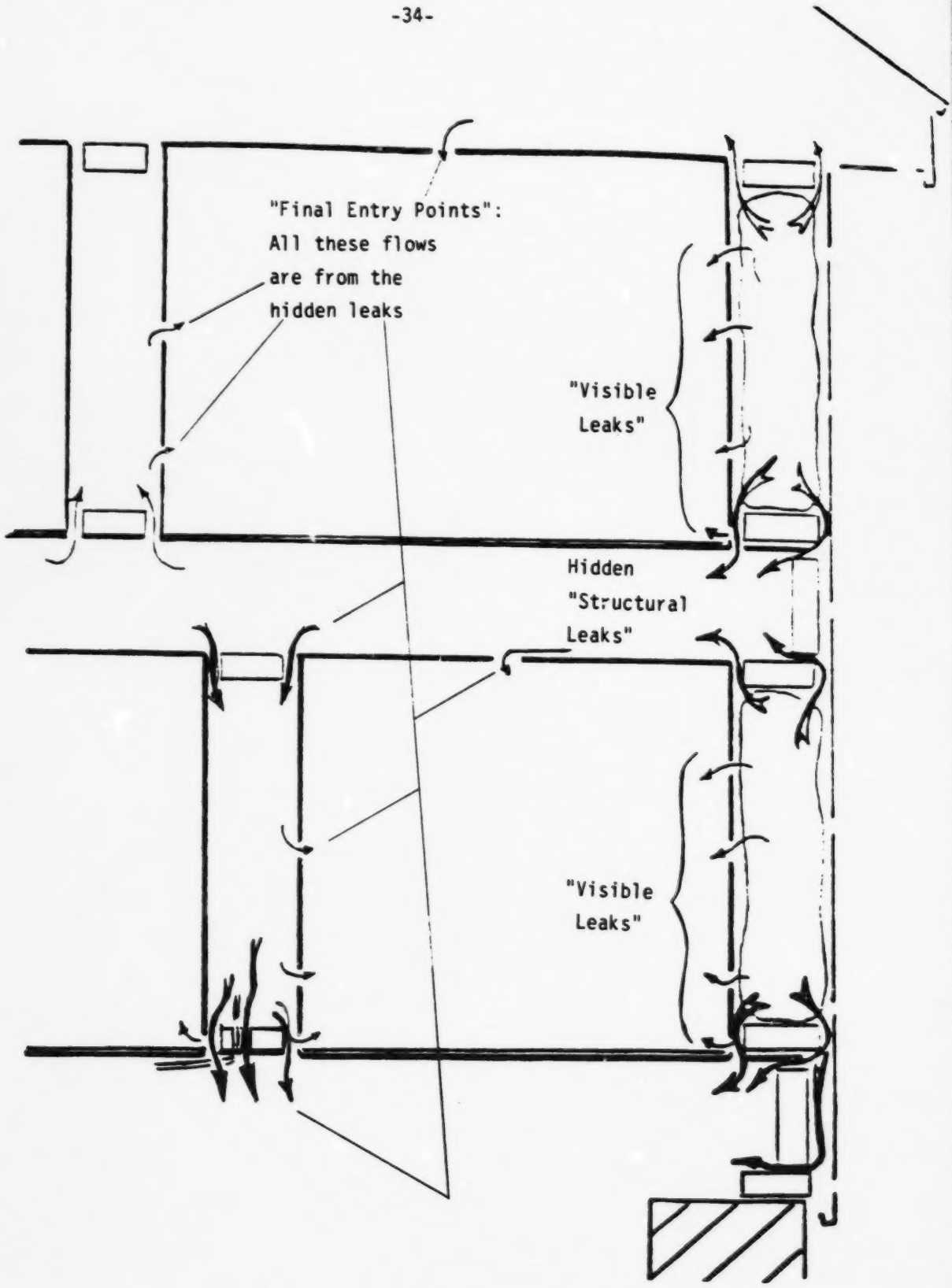


Fig. 1 Schematic of leaks from the UFFI'd cavities

Fig. 2 Wall-into-floor leaks

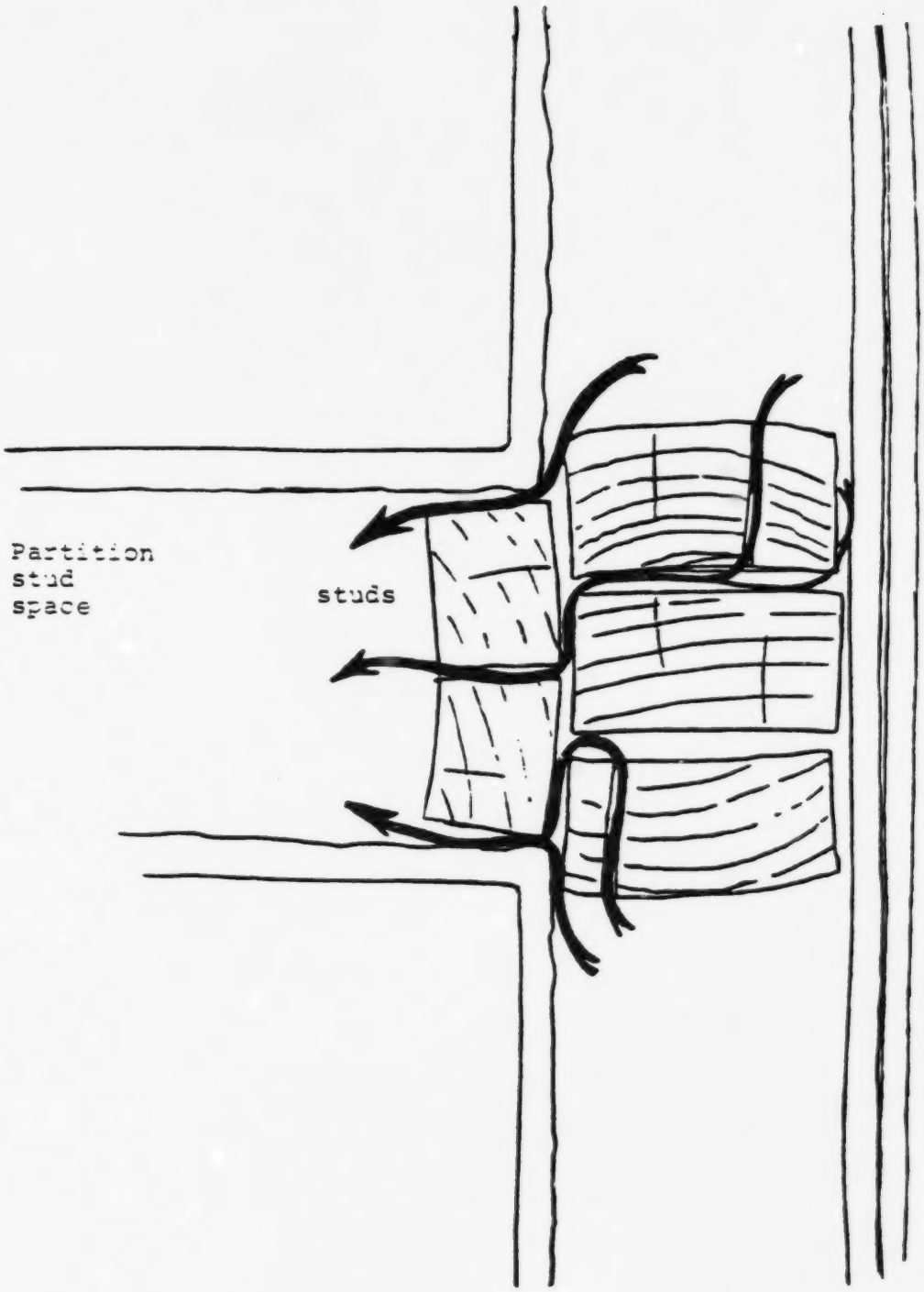


Fig. 3 Wall-into-partition leaks

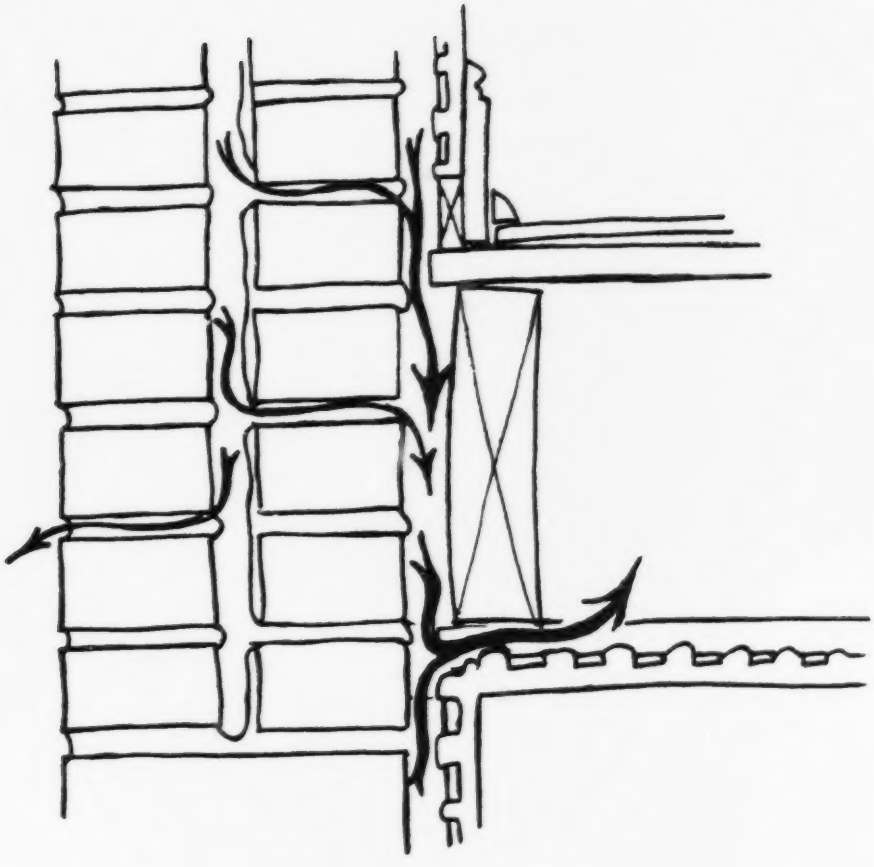


Fig. 4 Wall-into-floor gaps

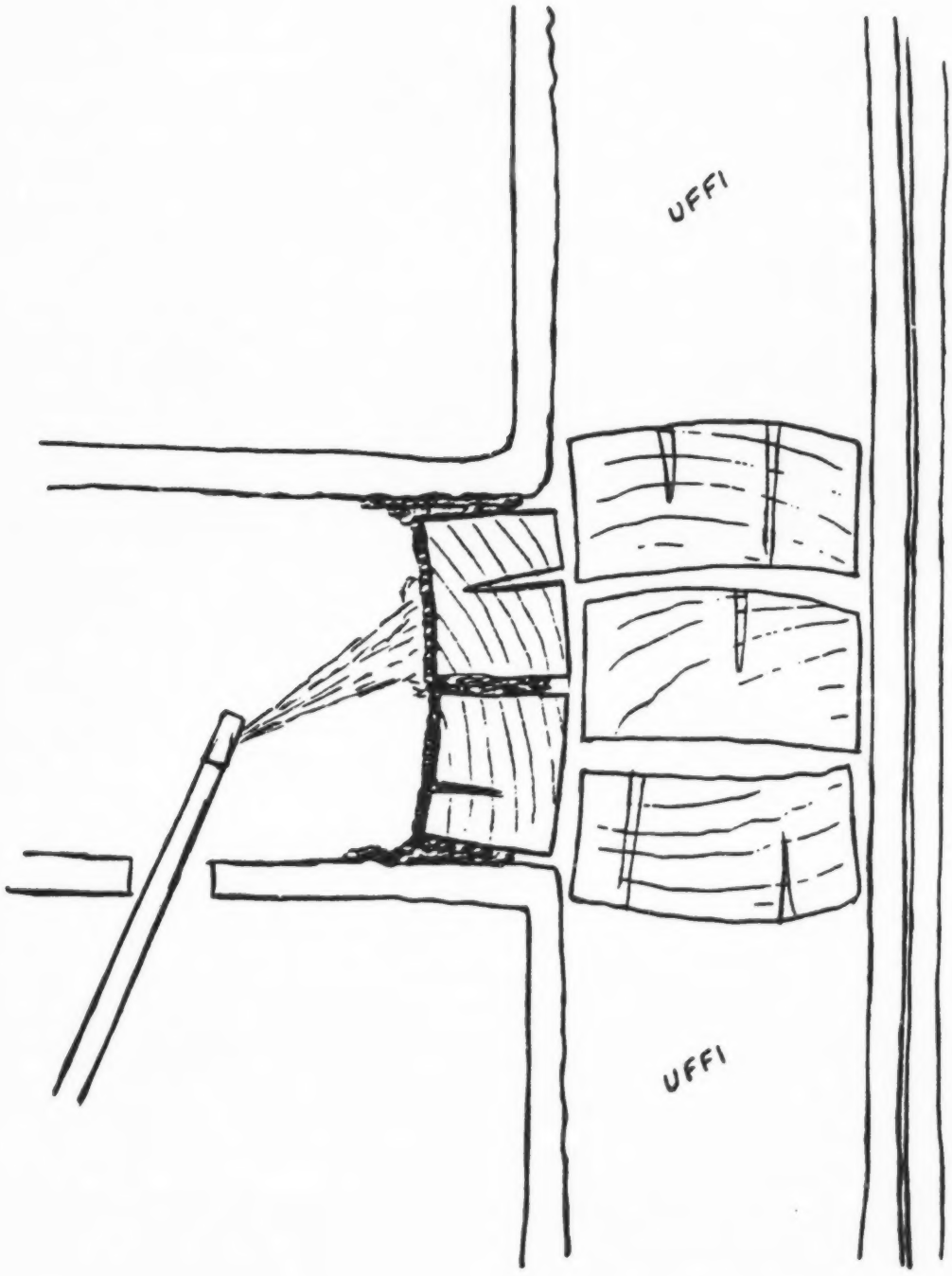


Fig. 5 Drill-and-spray sealing of shrinkage crack leaks (wall-into-partition, as Fig. 3)

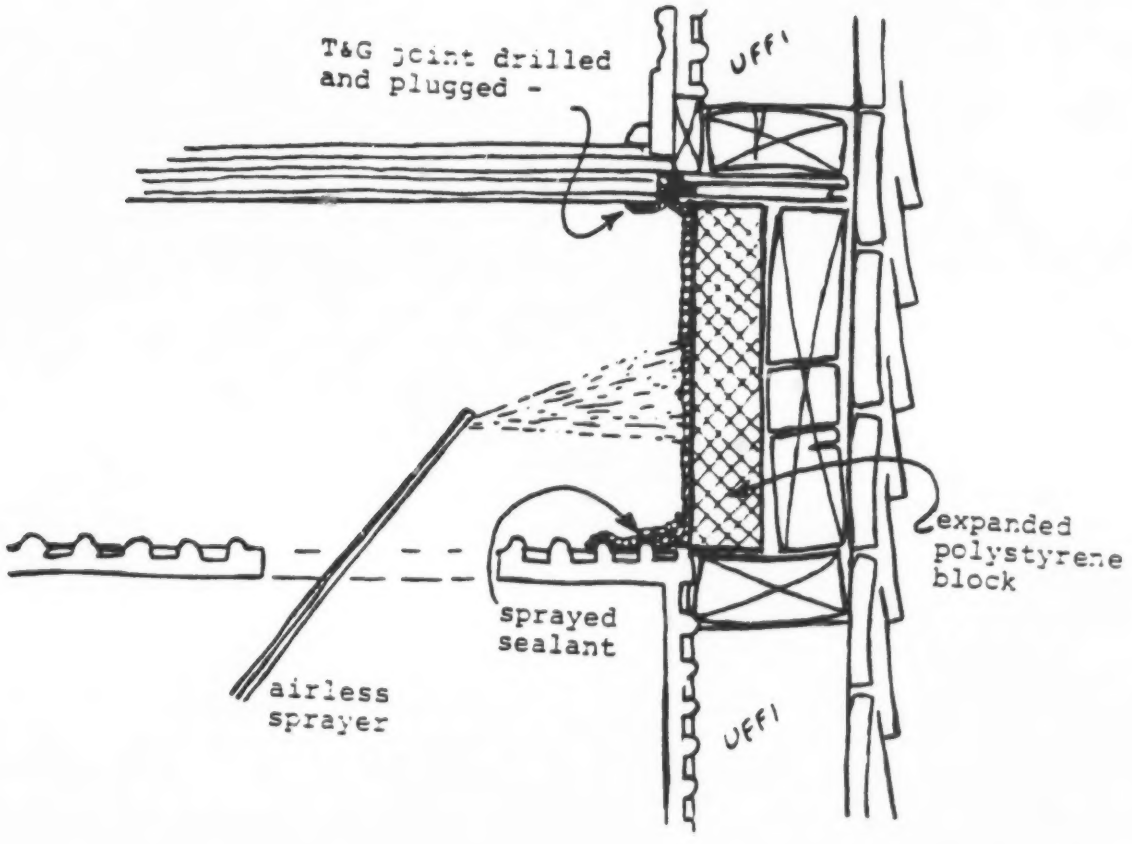


Fig. 6 "Open access" plugging and spray sealing

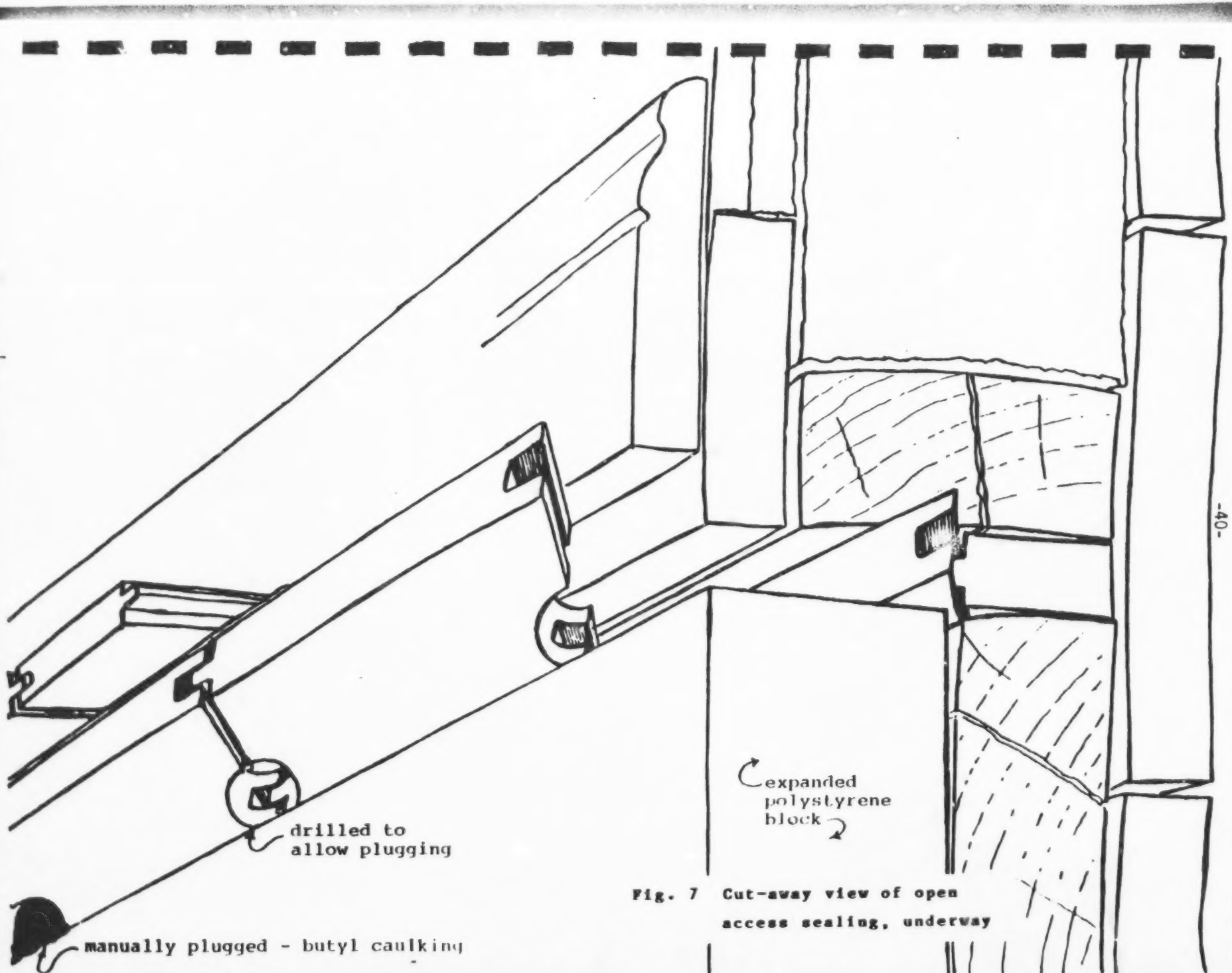


Fig. 7 Cut-away view of open access sealing, underway

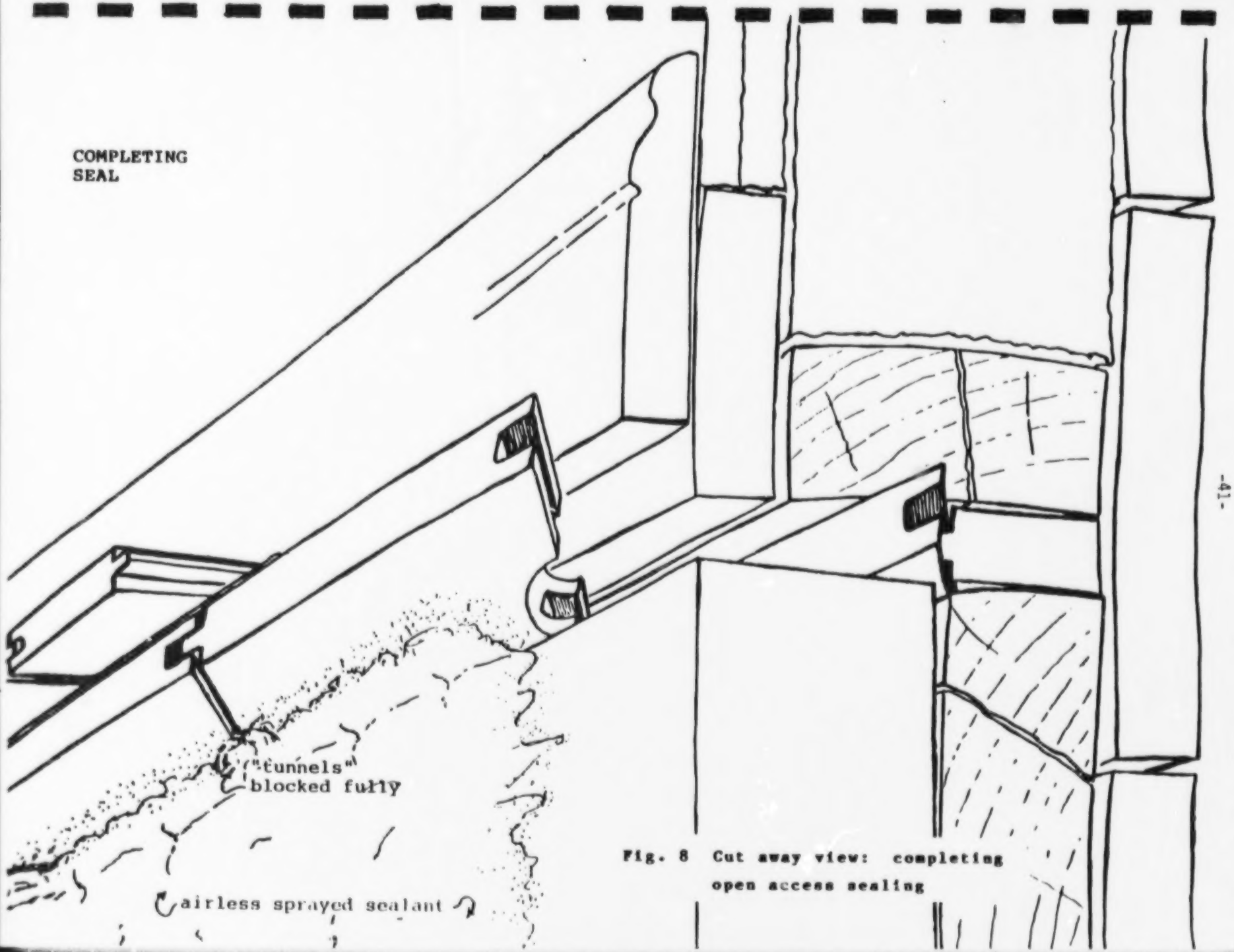


Fig. 8 Cut away view: completing open access sealing

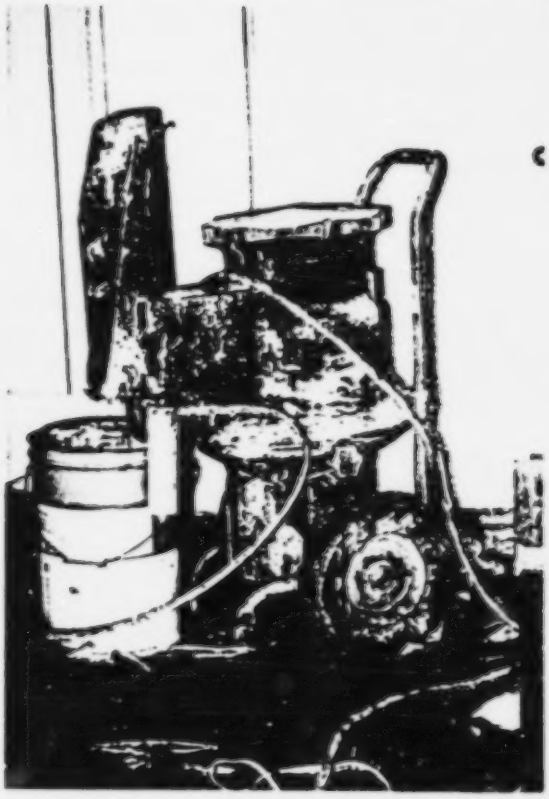


Fig. 9 Airless spray equipment

Fig. 10
"Borescope"
optical
fibrescope

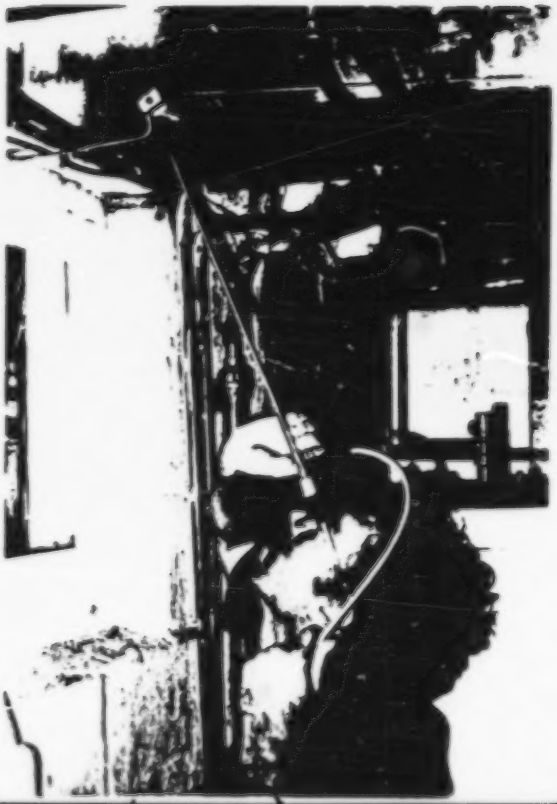
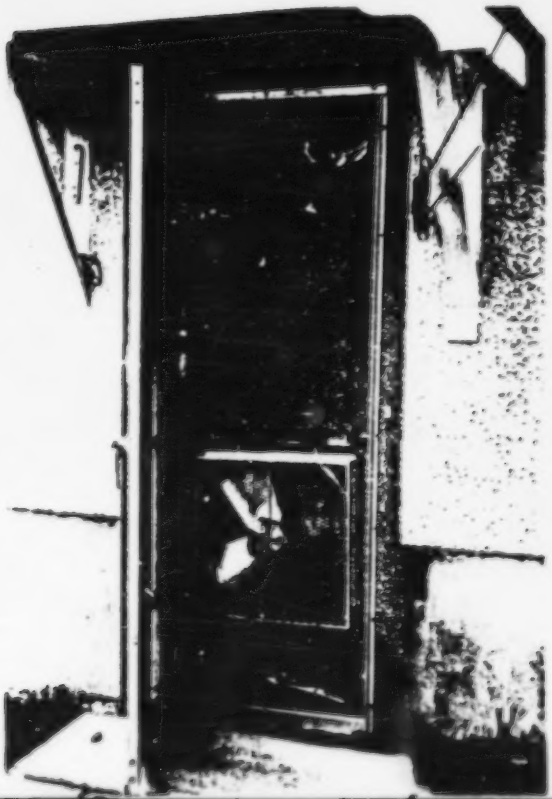
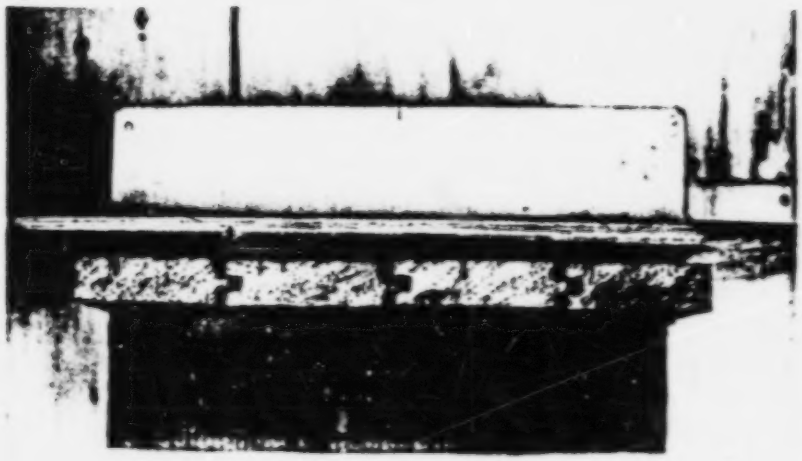
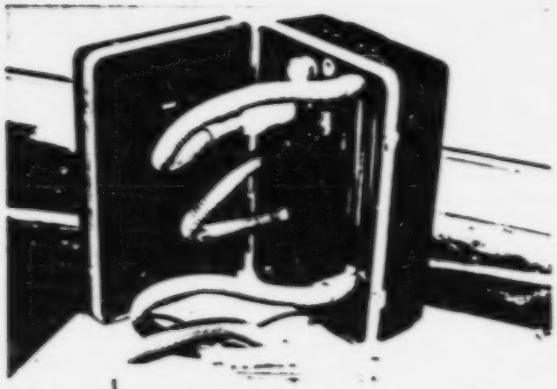


Fig. 11
"Infiltec" ↓
fan door







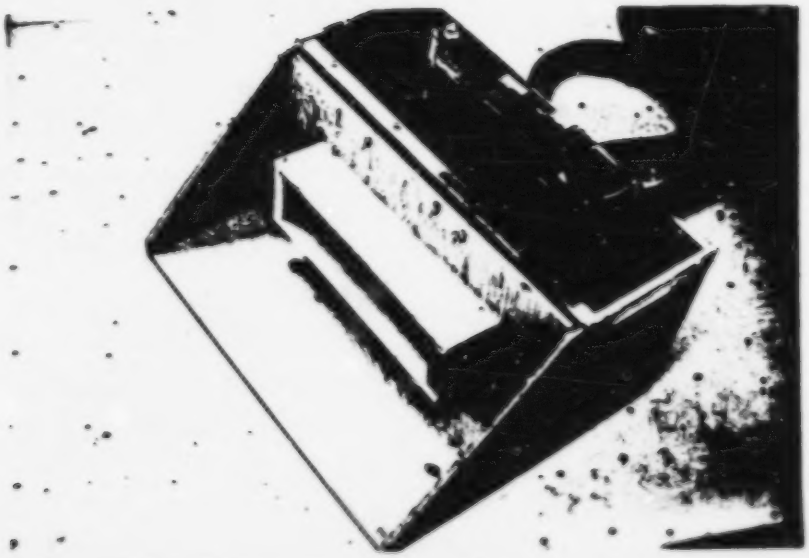


Fig. 12
Mock up of wall/floor (as Fig. 2) mounted in pressure/flow test rig.

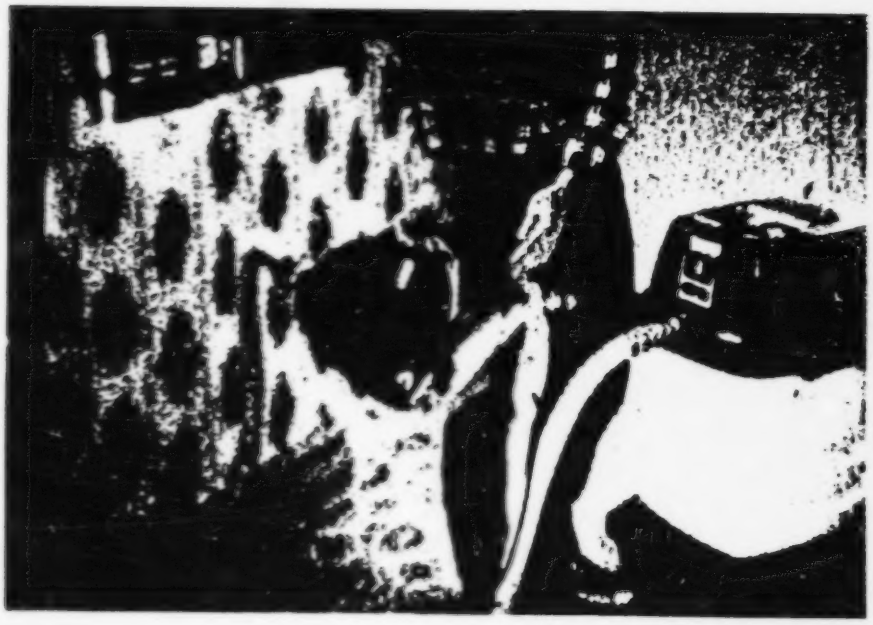


Fig. 13 "Dust-free saw" ready for use. See also. Fig. 21.

(Several of the photographs illustrating the field work have been enlarged from an 8 mm (super 8) colour movie film - hence their lack of sharp definition.)

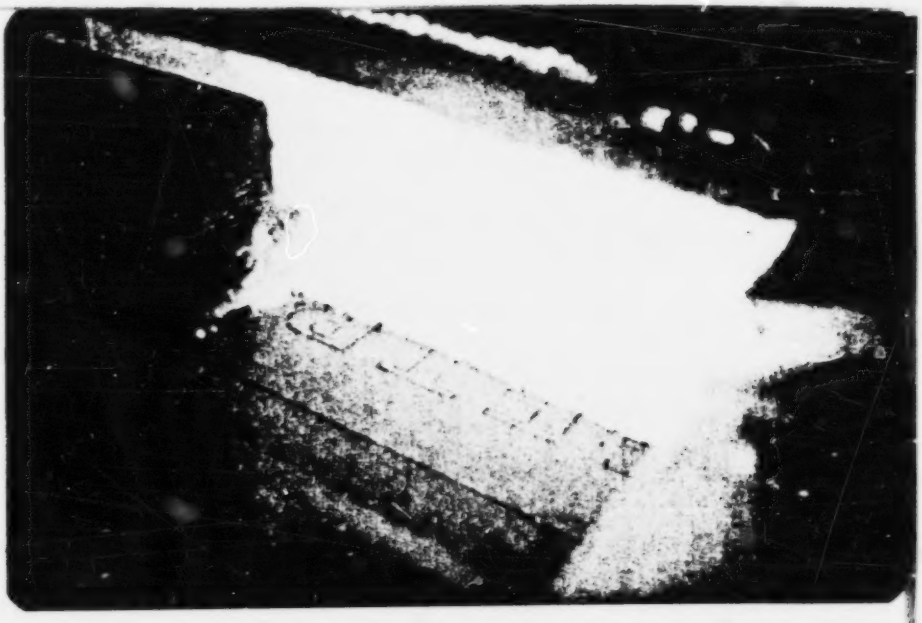


Fig. 14
Joist space under knee wall "bulk-headed" (rigid polystyrene)

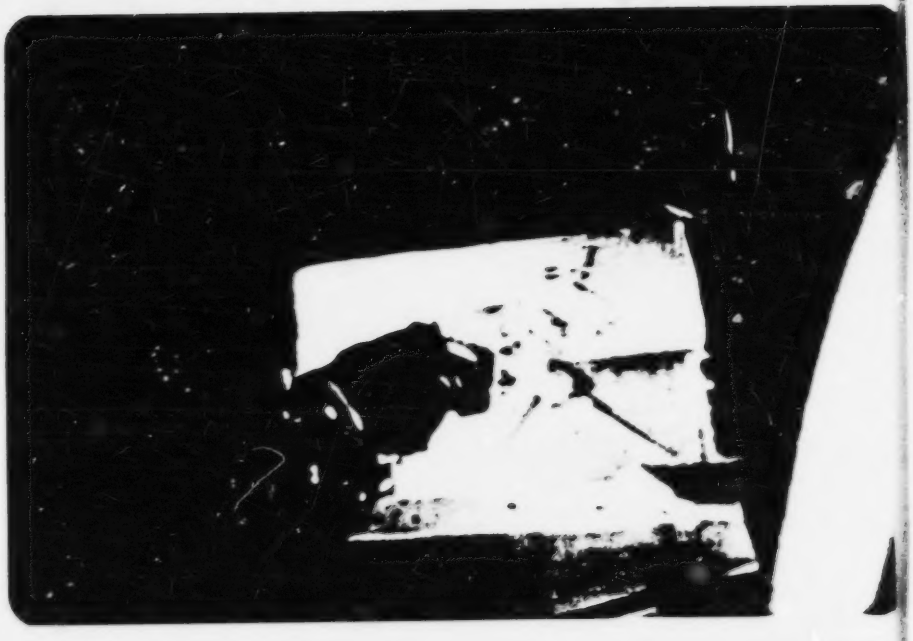


Fig. 15
Spray-sealing the above bulkhead

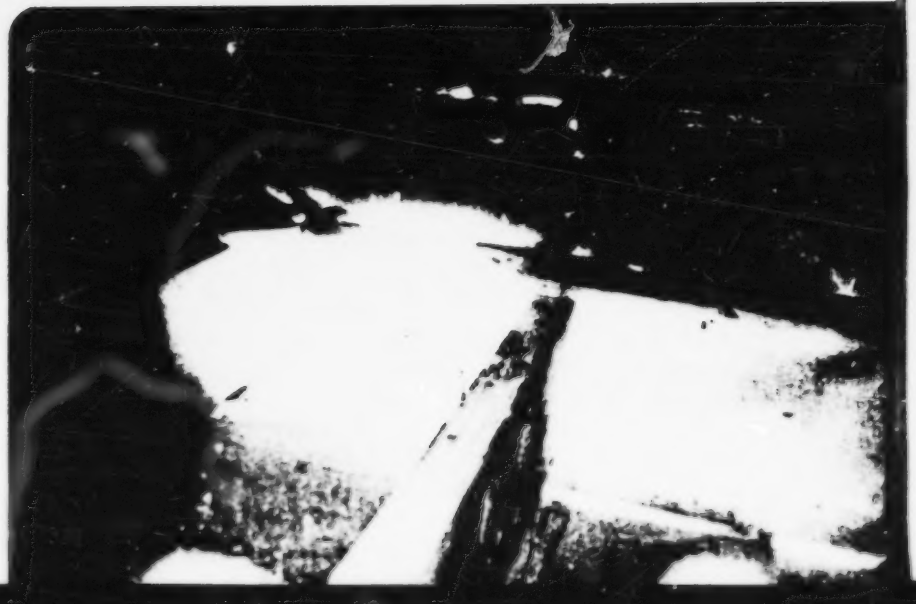


Fig. 16
Spray-sealing completed

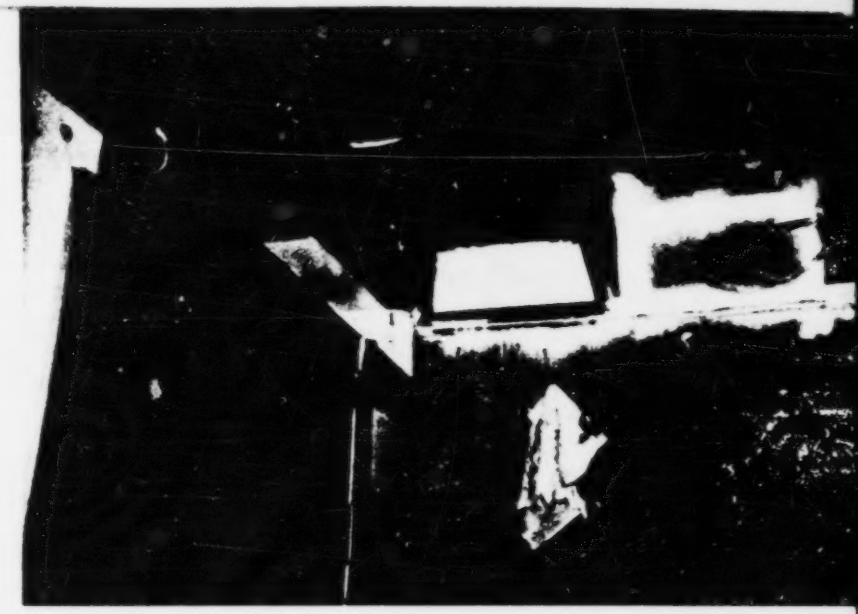


Fig. 17
Wall-into-basement seal entails opening return air duct.

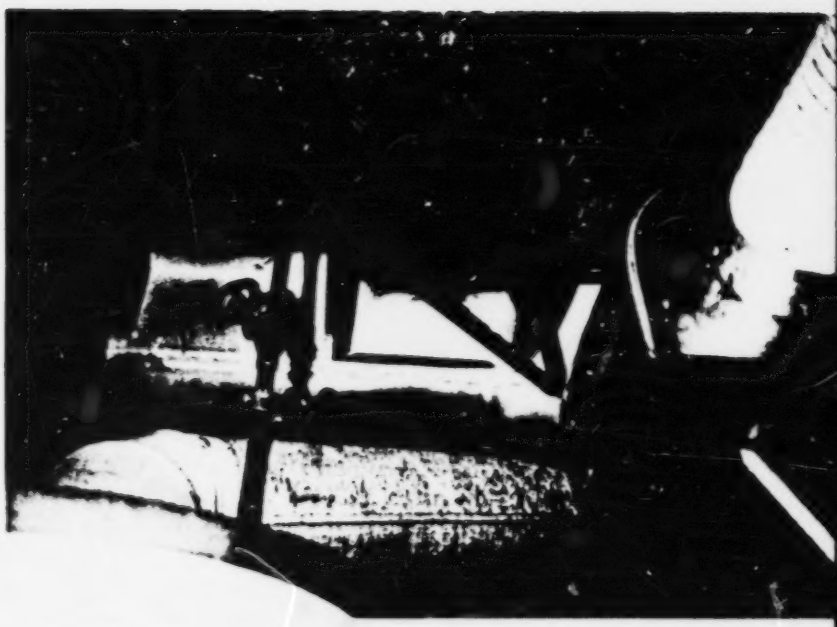


Fig. 18
Spray sealing can reach into cluttered areas.

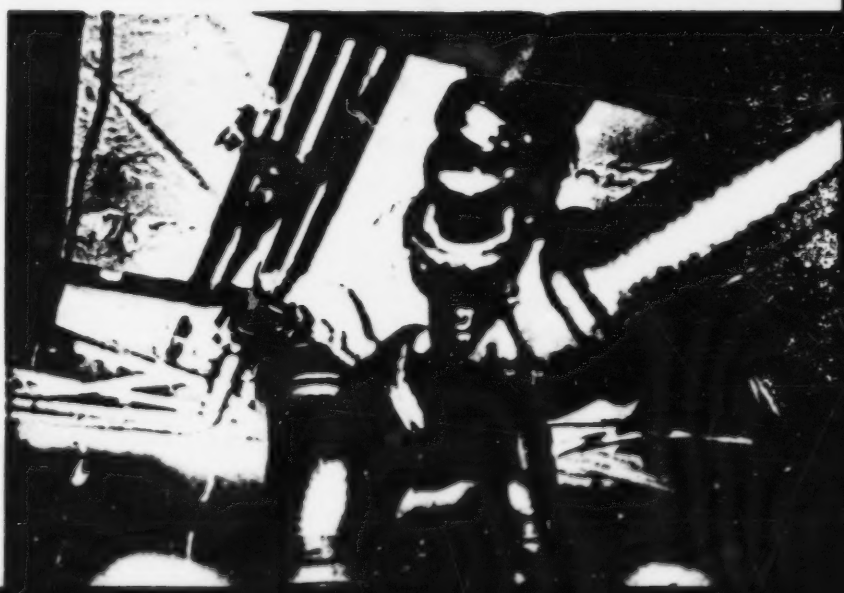


Fig. 19
Gaps stuffed with tightly rolled glass fiber insulation, then spray-sealed.

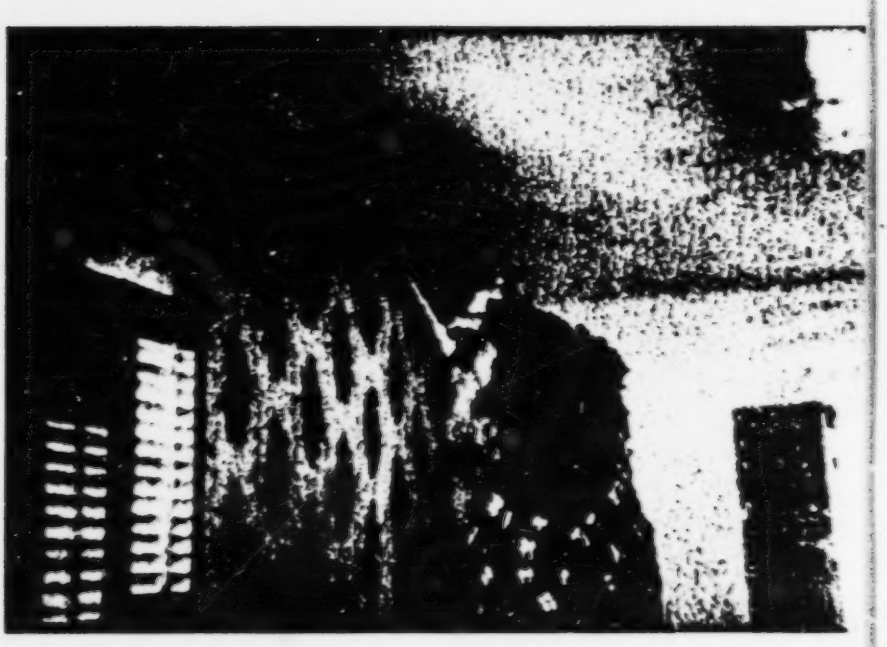


Fig. 20 Inspecting wall-into-floor leakage zone with optical fibrescope.

Fig. 21 Open access deemed necessary: dust-free saw in use.

Fig. 22 Removing the ceiling plaster.

Fig. 23 Removing rockwool insulation (the house began life as a bungalow with ceiling insulated).

Fig. 24 Capping the masonry wall with rigid polystyrene.

Fig. 25 Spray sealing the masonry wall (completely around and over the capping).

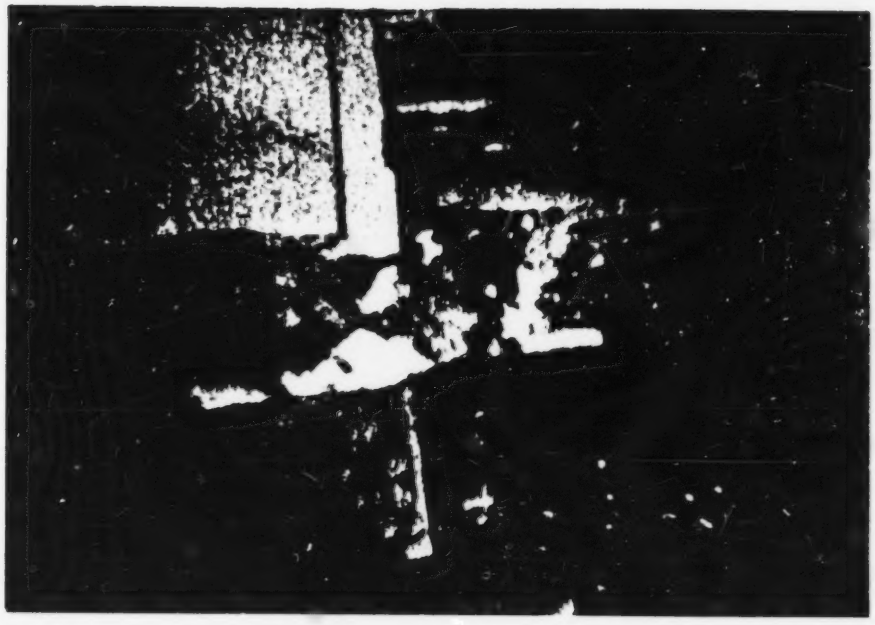
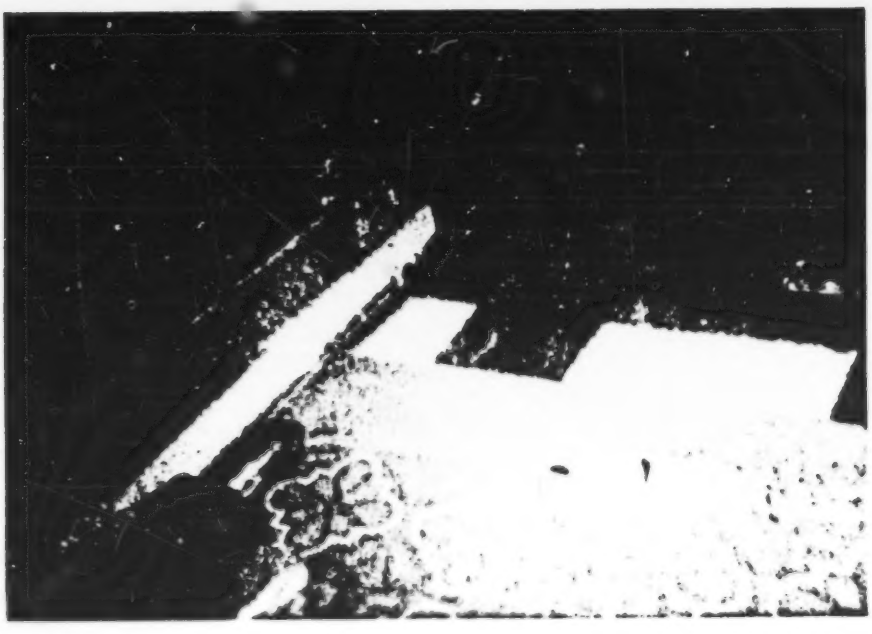


Fig. 26 Top of masonry wall revealed (stair landing opened). Note UFFI protrusions.

Fig. 27 Spray sealing masonry wall top through floor in knee-wall space.

Fig. 28 Capping the masonry wall, access through flooring. (Choice of access through floor vs. through ceiling below was taken for learning purposes.)

Fig. 29 Capping completed.



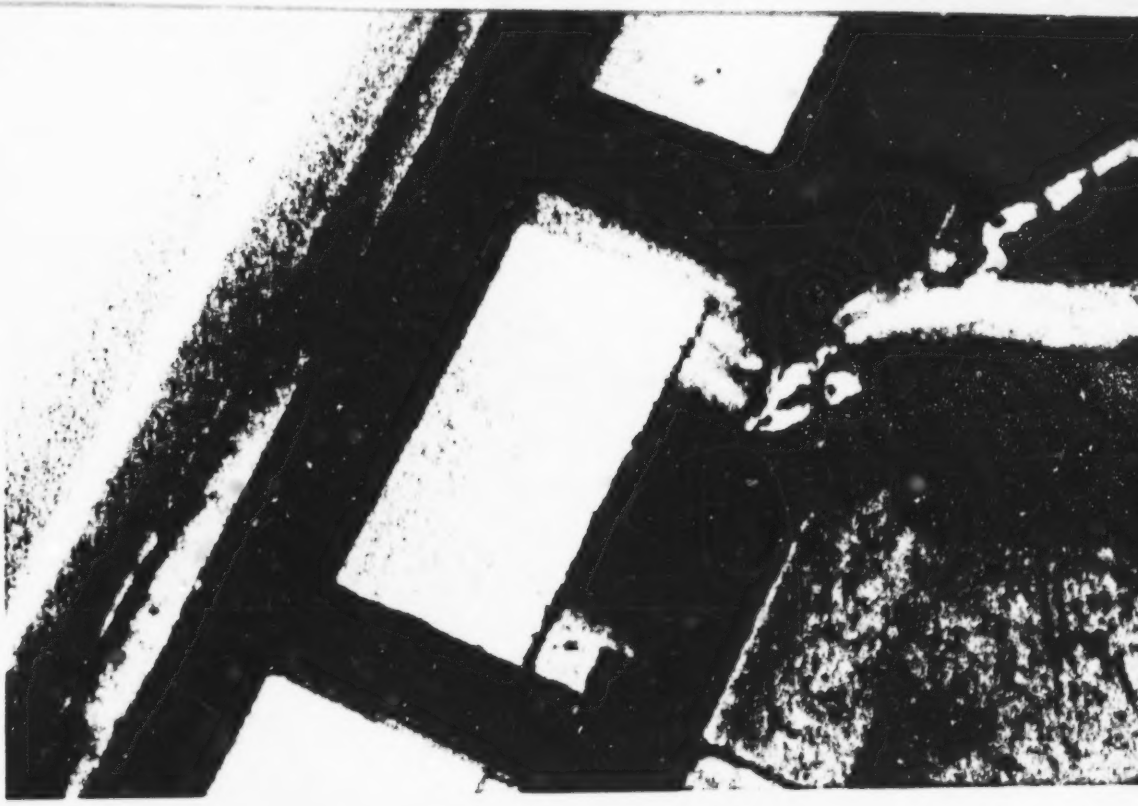
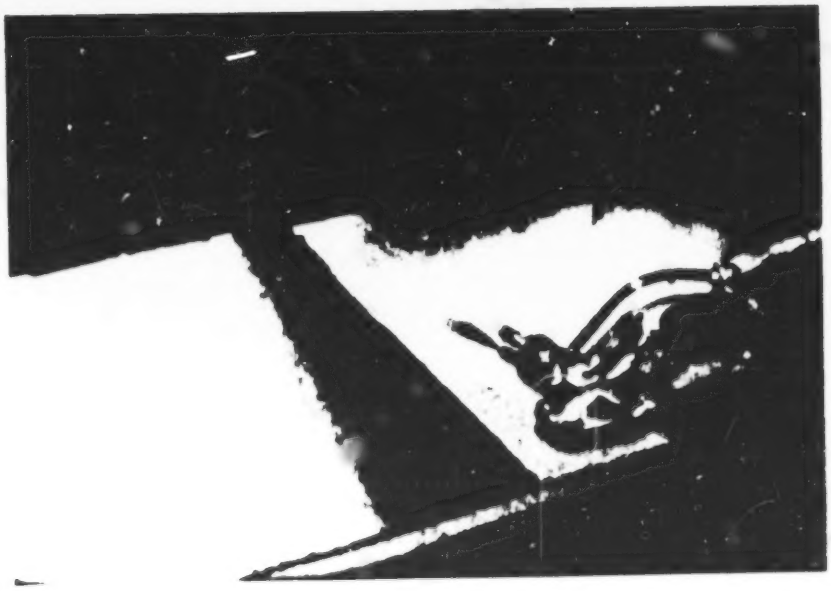


Fig. 30 Spray sealing the masonry wall top from above.

Fig. 31 Spray sealing the masonry wall top from above.



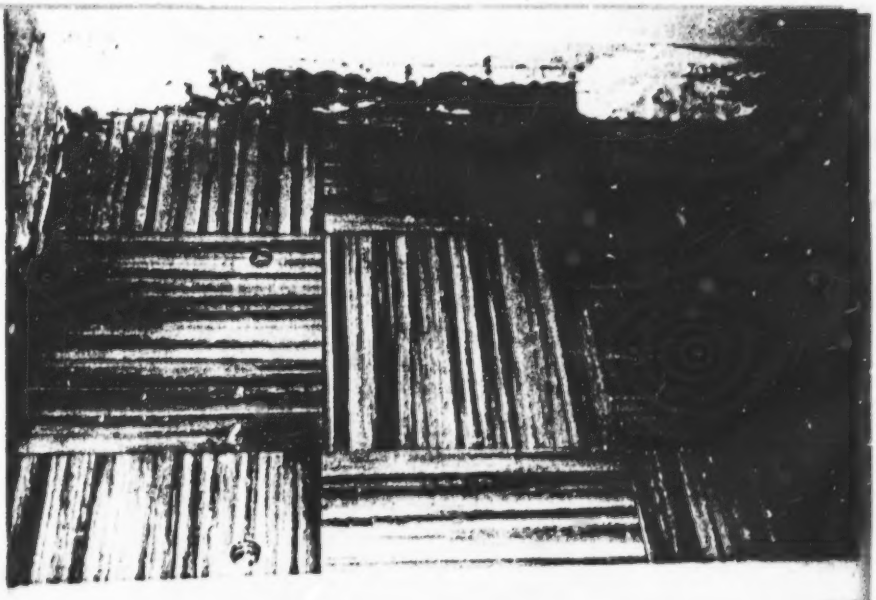


Fig. 32
Sleeper floor (and all ends of partitions) were drill-and-spray sealed.

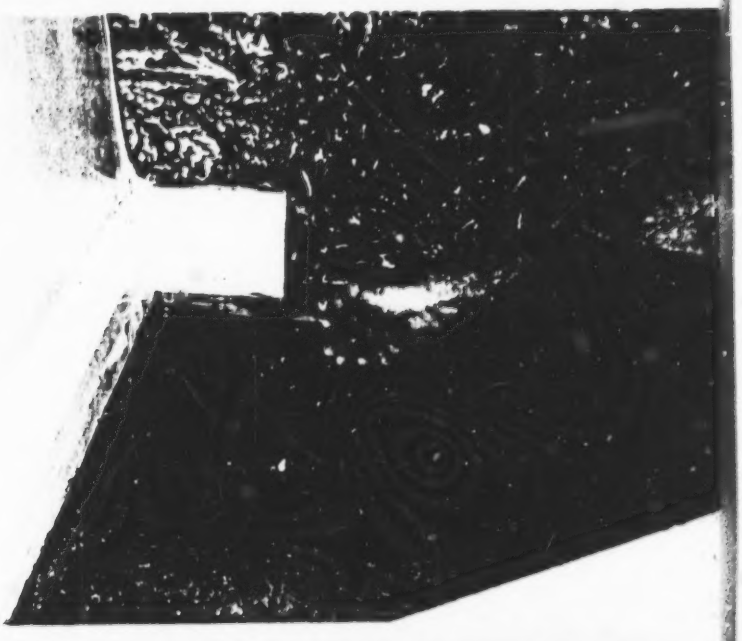


Fig. 33
Slab on grade sealed directly to wall (where no sleeper floor in the way).

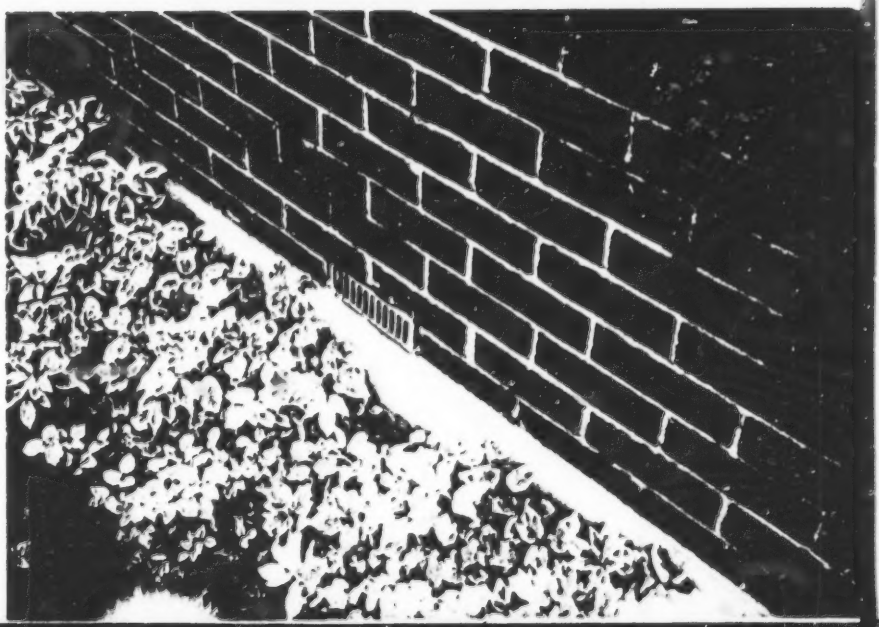


Fig. 34
Vents added to north wall to allow UFFI to dry.

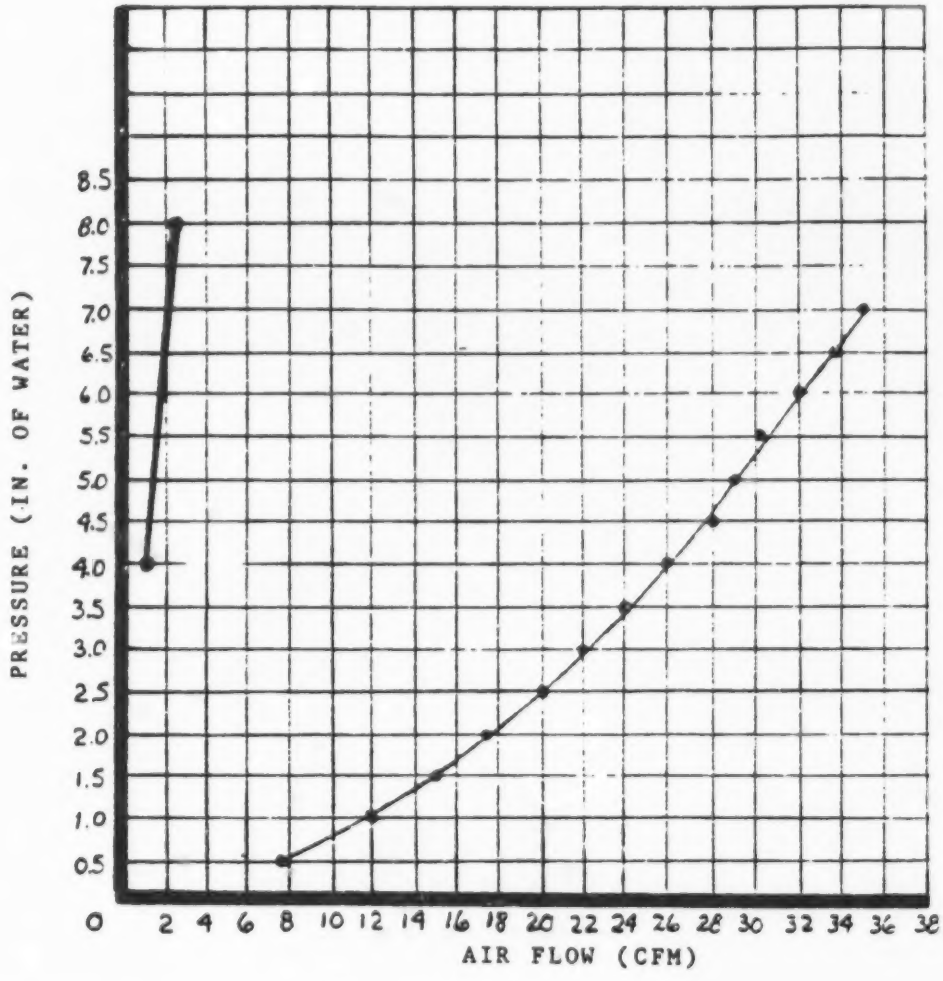


Figure 35: Typical pressure/flow graph of wall-into-floor coupon test.

(Mock-up No. 4 with square edge planking.)

POOR

QUALITY

ORIGINAL